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The evaluation of drivers' responses to a multi-characteristic power assisted steering system.

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DEDICATION

This thesis is dedicated to Katarzyna Malinowska for her understanding, support and encouragement during the final stages of its production.

ABSTRACT

A sample of fifty male and fifty female drivers took part in an experiment designed to evaluate a multi-characteristic power assisted steering system. Subjects drove a car fitted with the system for two one-hour periods on public roads and on two test-track sessions during which a number of driving performance variables including driving time and steering activity were recorded. Drivers completed a specially developed questionnaire after each road drive. A subsidiary task, which involved the visual monitoring of an illuminated display and verbal responses, was administered during the test-track sessions.

Factor analysis and discriminant analysis were used to analyse data from the questionnaire, road drives and test-track sessions. Data were first factor analysed and the factors subsequently used as variables in the discriminant analyses. It was possible to discriminate between male and female drivers, and between groups of drivers allocated to the different power steering characteristics on the basis of the discriminant functions derived. Thus, males were found to be more sensitive to the force feedback characteristics of the standard power steering than females, finding it difficult to judge the amount of effort required to steer the car and tending to 'over steer' under some circumstances. Males drove faster than the females on the Motorway with the standard power steering, however, more slowly than females in urban driving, and drove faster and more accurately than females on the test-track. On the basis of the differences observed between drivers allocated to the different power steering characteristics, criteria were developed which allowed the specification of that characteristic which could be considered 'optimal' for ordinary drivers of both sexes. This characteristic, termed "Speed Proportional Feel", provides the driver with full power assistance at low speeds, but increasingly inhibits the operation of the power assistance as vehicle speeds rise, giving more steering 'feel' at high speeds.

The test-track data were further analysed by means of the analysis of variance and analysis of covariance. The results of the analysis of variance indicated that the presence of the subsidiary task had affected drivers' performance on the test-track. Analysis of covariance was used to provide a statistical control for the effects of the subsidiary task on drivers' primary task performance and a significant learning effect was observed. No significant differences were found in the number of subsidiary task responses made by drivers allocated to different steering characteristics.

A recommendation was made for further research into the observed differences between males' and females' driving speeds which, it was suggested, may be related to the types of accident in which males and females are typically involved. Further research into the level of artificial 'feel' favoured by male and female drivers was also recommended on the basis of the finding that females appeared to respond more favourably to a lower level of 'feel' than males.

CONTENTS

Volume 1 — Page

FIGURES

1. INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The work reported in this thesis was carried out in fulfilment of a contract between the School of Automotive Studies, Cam Gears Ltd., and the Ford Motor Company. The purpose of the work was to conduct a human factors evaluation of a multi-characteristic power assisted steering system developed by Cam Gears and fitted to a Ford car. In order to provide a clear understanding of the need for such an evaluation and to indicate the nature of the issues to be addressed, the background of the project is reviewed briefly in the following paragraphs.

For some years prior to the commencement of the project, Cam Gears had been developing prototype power assisted steerinc systems with novel response characteristics. These prototype systems differed from conventional power assisted steering systems in terms of their force feedback characteristics, and each represented an attempt to provide the driver with a degree of steering 'feel', a property which is generally considered to be lacking in conventional power steering. (The concept of steering 'feel' is discussed in depth in later sections.) It was important, therefore, for Cam Gears to discover whether their prototype power steering systems would be perceived by ordinary drivers as having any advantages over their conventional production systems. If it could be demonstrated that one or other of the prototype systems was perceived by drivers as 'better' in some sense than convention power steering, then Cam Gears would be in a position to recommend such a system to their customers, the vehicle manufacture

The School of Automotive Studies was, at this time, actively involved in the investigation of drivers' psychological and physiological responses to a number of vehicle handling variables. For example, Campos and Robertson (1971) had developed a testing procedure to establish acceptable steering forces and rates of steering wheel movement for drivers of Public Service Vehicles. In a series of experiments carried out for the Transport and Road Research Laboratory, Ellis, Read and Liddiard (1976) investigated drivers' reactions to temporary loss of vehicular control and to changes in the vehicle's handling characteristics brought about by the manipulation of tyre pressures. A mathematical model for the computer simulation of vehicle motion under loss of control conditions was also developed by these authors. Finally, Wilson and Anderson (1980) reported on the effects of tyre type on drivers' choice of speed and presumed risk-taking in test-track and open road driving. The School was, therefore, in a good position to extend its work on drivers' responses to vehicle handling characteristics into the area of power assisted steering in cars.

The Ford Motor Company was approached as a possible source of financial support for the study because it currently fitted Cam Gears' power steering systems to its larger cars, and it was thought that Ford would, therefore, be interested in the evaluation of alternative, and possibly improved, power steering systems. Ford subsequently expressed considerable interest in the project, particularly with respect to the methods which it was proposed to develop for the subjective assessment of the multi-characteristic system by ordinary drivers. In line with the practice of other vehicle manufacturers, Ford traditionally employs expert test drivers to evaluate its vehicles, and it readily appreciates that this method is likely to result in a biased and unrepresentative view of the effects of design changes on members of the driving public. Ford viewed the development of a systematic and rigorous method of subjective evaluation as a valuable product of the project, therefore, and agreed to support the study.

Thus, the impetus for the work reported here was provided from three sources. Firstly, Cam Gears had developed a number of prototype power steering systems with novel characteristics which they believed would provide the driver with more steering 'feel'. (These prototype systems were later combined into a single multi-characteristic system for experimental use.) Their immediate requirement was to discover whether drivers would perceive any beneficial effects of the prototype systems over those of conventional power steering. Ultimately, if it could be demonstrated that one of the prototype systems represented an improvement over conventional systems, Cam Gears would be in a position to recommend that system to its customers. Secondly, the School of Automotive Studies had considerable experience in the investigation of drivers' responses to vehicle handling characteristics, and wished to extend its investigations into the area of power assisted steering in cars. Finally, the Ford Motor Company were interested in the evaluation of power steering characteristics by ordinary drivers not only from the point of view of improving the power steering on their production vehicles, but also from the point of view of the assessment techniques to be developed for such an evaluation.

It was formally agreed, therefore, that Cam Gears would provide the multi-characteristic power assisted steering system to be used in the study, that the School of Automotive Studies would provide the testing facilities and personnel necessary to carry out the study, and that the Ford Motor Company would provide sufficient financial support for the provision of a suitable test vehicle and a contribution towards its running costs. It was further agreed that the author, a student in the School of Automotive Studies' Applied Psychology Unit, would be given the responsibility for all aspects of the study's design and implementation, and that he would be free to report the work in his Ph.D thesis.

It was recognised at the outset that the evaluation, by ordinary drivers, of a multi-characteristic power steering system in order to identify that characteristic which could be considered 'optimal' in some sense would not be an easy task. Previous experience in the field of driver behaviour indicated that a great many variables influence the way in which the driving task is performed, and that those variables associated with vehicle handling contribute relatively little to the total amount of variance seen in drivers' performance. In order to identify that part of the variance due to the characteristics of power assisted steering, it would clearly be necessary to pay careful attention both to the choice of dependent measures and to the conditions under which drivers were to be observed. Consequently, considerable effort was directed to the development of a suitable methodology for the study, and this is described in detail in a later section.

Before the study itself is reported, it is necessary to review the problems associated with power assisted steering and to discuss the ways in which these problems were addressed by the designers of the Cam Gears multi-characteristic power steering system. This review and discussion is presented in the following sections.

1.2 FACTORS AFFECTING THE PHYSICAL EFFORT REQUIRED TO STEER A CAR

In order to understand the need for power assisted steering, the problems associated with it and the effects of power assisted steering on the driver, it is necessary to consider certain basic principles of vehicle dynamics and some aspects of steering system design. Since the purpose of power assisted steering is to avoid the imposition of otherwise excessive steering loads on the driver, this discussion will focus on those factors which affect the physical effort required to steer a car.

When the driver turns the steering wheel of a moving car, the front wheels are set at an angle to the direction of travel of the car, and a cornering force is generated between the tyres and the road. Normally, only the front wheels of the car are steered, so that the cornering forces generated at the front wheels are greater than those generated at the rear wheels, and the car begins to turn, or 'yaw', that is, to rotate about on axis running vertically through its centre of gravity.

The car's tyres meet the road at their 'contact patches', and because the tyre cornering forces do not act at the centre of the contact patches, but at some distance to the rear of them, self-aligning torques are generated which act to oppose the effort being applied by the driver at the steering wheel (see Figure 1). Thus, the driver, having set the front wheels at an angle to the direction of travel by applying a force to the rim of the steering wheel, must continue to apply a force as the vehicle 'yaws' to overcome the self-aligning torques being generated at the front wheels which are trying to realign the front wheels with the direction of travel. The magnitude of self-aligning torque the driver will need to overcome in steering the car will in turn depend upon several things. The most important of these for the present discussion are the tyre loads, (the weight of the vehicle acting on the front tyres), the angle at which the front wheels are set to the direction of travel, and the forward speed of the car.

1.2.1 TYRE LOADING

The relationship between tyre loading and self-aligning torque is due mainly to the increased cornering force generated for a given steering input as tyre loading, or vehicle weight, is increased. All other things being equal, heavier cars require more effort from the driver to steer them. This is especially noticeable at very low speeds, for example, when parking, as cornering force is also related to forward speed as indicated below.

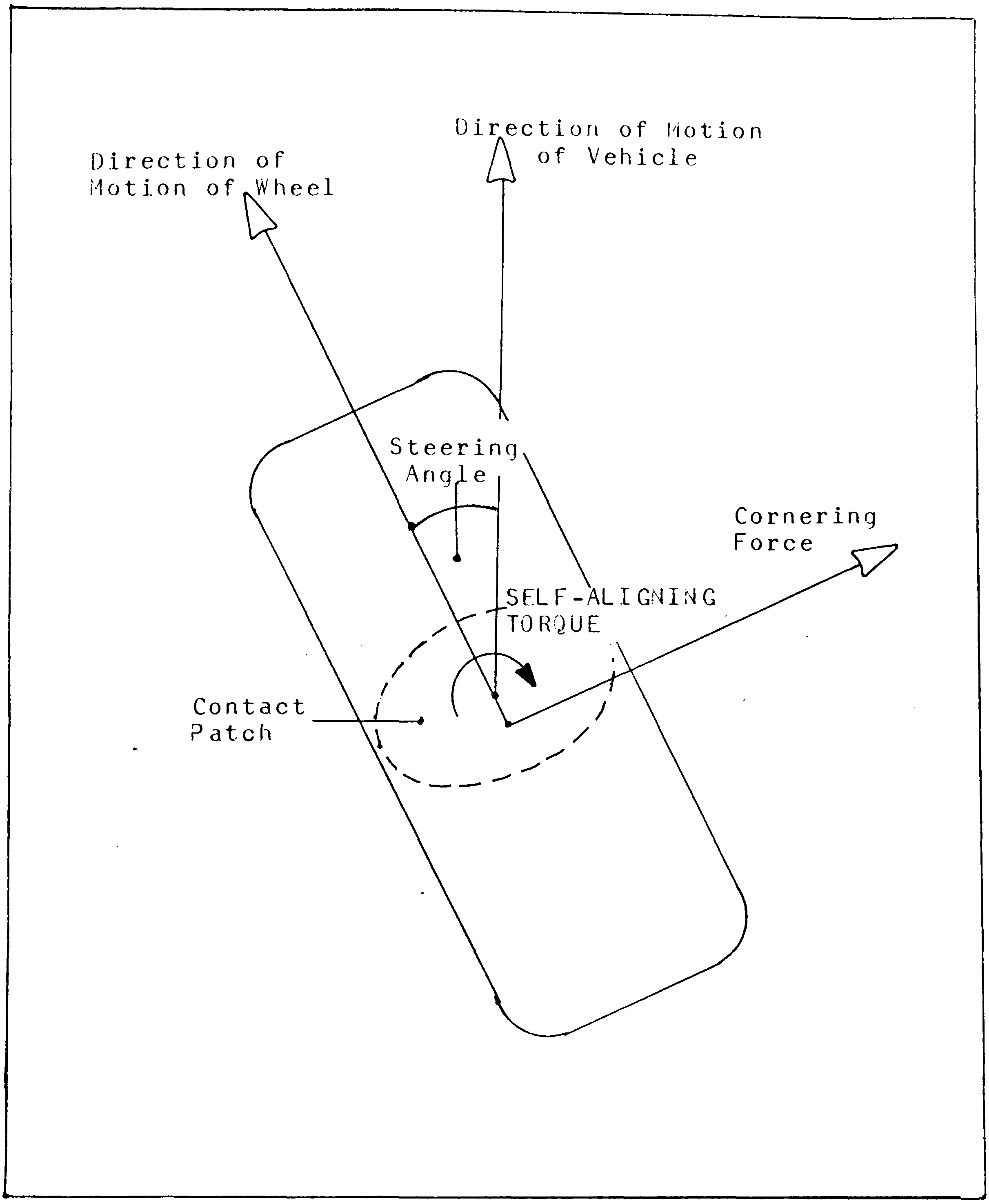

FIGURE 1. Simplified diagram to illustrate how the cornering force generated by the tyre acts to re-align the wheel with the vehicle direction of motion.

1.2.2 FRONT WHEEL ANGLE

The relationship between the angle at which the front wheels are set to the direction of travel and the cornering forces and self-aligning torques generated, is a relatively simple (linear) one for low to moderate cornering forces. For a given vehicle forward speed, cornering forces and self-aligning torques increase with front wheel angle. As the tyre's maximum available cornering force is approached, however, the cornering force tends to act closer to the centre of the tyre's contact patch, with the result that the self-aligning torque is dramatically reduced. The effect is to make the steering suddenly feel very light.

The reduction of self-aligning torque as the tyre's maximum cornering force is reached is important, since it is often claimed that it serves as a useful warning to the driver who will sense or 'feel' the lightening of the steering under these conditions. The topic of steering 'feel' is discussed further later in this Introduction.

1.2.3 VEHICLE SPEED

As mentioned previously, the cornering forces, and therefore the self-aligning torques generated at the front wheels depend upon the vehicle's forward speed. In general, the faster the car is travelling, the higher the cornering force generated for a given front wheel angle. Expressed in a slightly different way, this relationship between cornering force and forward speed means that as vehicle speed increases, a smaller front wheel angle, and therefore smaller steering wheel displacement, is required to produce the same cornering forces.

In addition, however, a significant amount of friction or 'scrubbing' is generated between the front tyres and road surface, and this is accompanied by a 'jacking up' effect as the suspension geometry raises the front of the car slightly when the wheels are turned through large steering angles. Consequently, the steering loads imposed upon the driver are relatively higher when he is driving at low speeds, for example, when parking, and these reach a peak when the car is stationary.

1.2.4 STEERING RATIO AND STEERING WHEEL DIAMETER

In addition to the effects of tyre loading, front wheel angle and vehicle speed referred to above, the car's steering ratio and the diameter of the steering wheel also influence the steering loads imposed on the driver.

The car's steering ratio may be defined in a number of ways, but essentially it is an index of the angular displacement of the steering wheel in relation to the angular displacement of the front (steered) wheels of the car. A numerically high ratio, for example 25:1, would indicate that the steering wheel displacement required to effect even modest angles at the front wheels is large. Conversely, a numerically low steering ratio, for example 13:1, would be considered relatively direct and would produce large steer angles at the front wheels for a relatively small steering wheel displacement

The steering ratio is important to the driver for two reasons. As mentioned above, the car's steering ratio in part determines the amount of effort required to turn the steering wheel. A numerically low steering ratio has the effect of increasing the effort required to turn the steering wheel whilst reducing the required displacement. A numerically high ratio has the opposite effect of reducing the effort required but increasing the necessary displacement of the steering wheel to turn the front wheels through a given steering angle. Thus, not only does the choice of steering ratio affect the amount of force the driver will need to apply to the steering wheel in steering the car, it also affects the distance through which he will be required to apply that force.

If the vehicle designer feels that the effort required to steer a particular car is too high, therefore, he is free to choose a numerically higher steering ratio to reduce the required effort. At the same time however, the increased steering wheel displacement made necessary by the new ratio may also be unacceptable. If, for example, the new ratio requires in excess of four revolutions to turn the road wheels between their maximum positions left and right, the driver might find it difficult to apply sufficient steering wheel displacement rapidly enough to steer the car in an emergency situation. In this case, altering the steering ratio to reduce the force required to steer the car would not be an appropriate solution.

The relatively higher efforts implied by a numerically low steering ratio can be overcome, or at least mitigated, by increasing the diameter of the car's steering wheel. The effect is to increase the distance at which the force applied by the driver at the rim is acting, thereby increasing the torque applied to the steering input shaft. The applicability of this option is also limited by space considerations and the awkwardness in use of wheels with greater than about 42 cm diameter.

1.3 POWER ASSISTED STEERING

In situations where excessive steering loads are anticipated, and the vehicle designer feels that a numerically higher steering ratio is not an appropriate solution, he may consider using power assisted steering.

Power assisted steering first became widely used by manufacturers in the United States, where passenger cars have traditionally been larger and heavier than their European counterparts. (As noted previously, heavier cars are associated with higher tyre loadings, and consequently, they impose greater steering loads on the driver.) The 'luxury' car makers in Great Britain, for example Rolls

Royce, Aston Martin and Jenson, have also employed power assisted steering as standard equipment for many years. Increasingly, however, the high volume manufacturers, notably Ford, British Leyland and Vauxhall, have also adopted power assisted steering as standard equipment or as an optional 'extra' on their larger cars. With the current trend towards front-engined, front wheel drive vehicles, in which the transmission is mounted beneath the engine, the consequent increase in steered wheel loadings has led at least one British manufacturer to develop power assisted steering for a relatively small (1300 cc engined) passenger car.

There are a number of different types of power assisted steering system currently in use, although each employs the same basic principles of operation. Essentially, the manual steering effort applied by the driver is supplemented in power assisted steering systems, by hydraulic pressure acting on a piston located in the steering linkage or within the steering gear itself. The various systems developed differ primarily in terms of the type of steering gear employed, the position of the actuating piston, and the type of valve used to control the flow of hydraulic fluid to the piston. (The hydraulic fluid itself is supplied under pressure from a reservoir via an engine-driven pump.) All power assisted steering systems, however, produce the maximum amount of power assistance when the vehicle is stationary, since it is under these conditions that the greatest steering effort is required from the driver.

To illustrate the relationship between the steering effort required from the driver and the level of assistance provided by the power steering system, the system characteristics can be shown on a graph in which steering wheel torque (the driver's input) is plotted against system pressure (the system output). A typical curve is given in Figure 2 below.

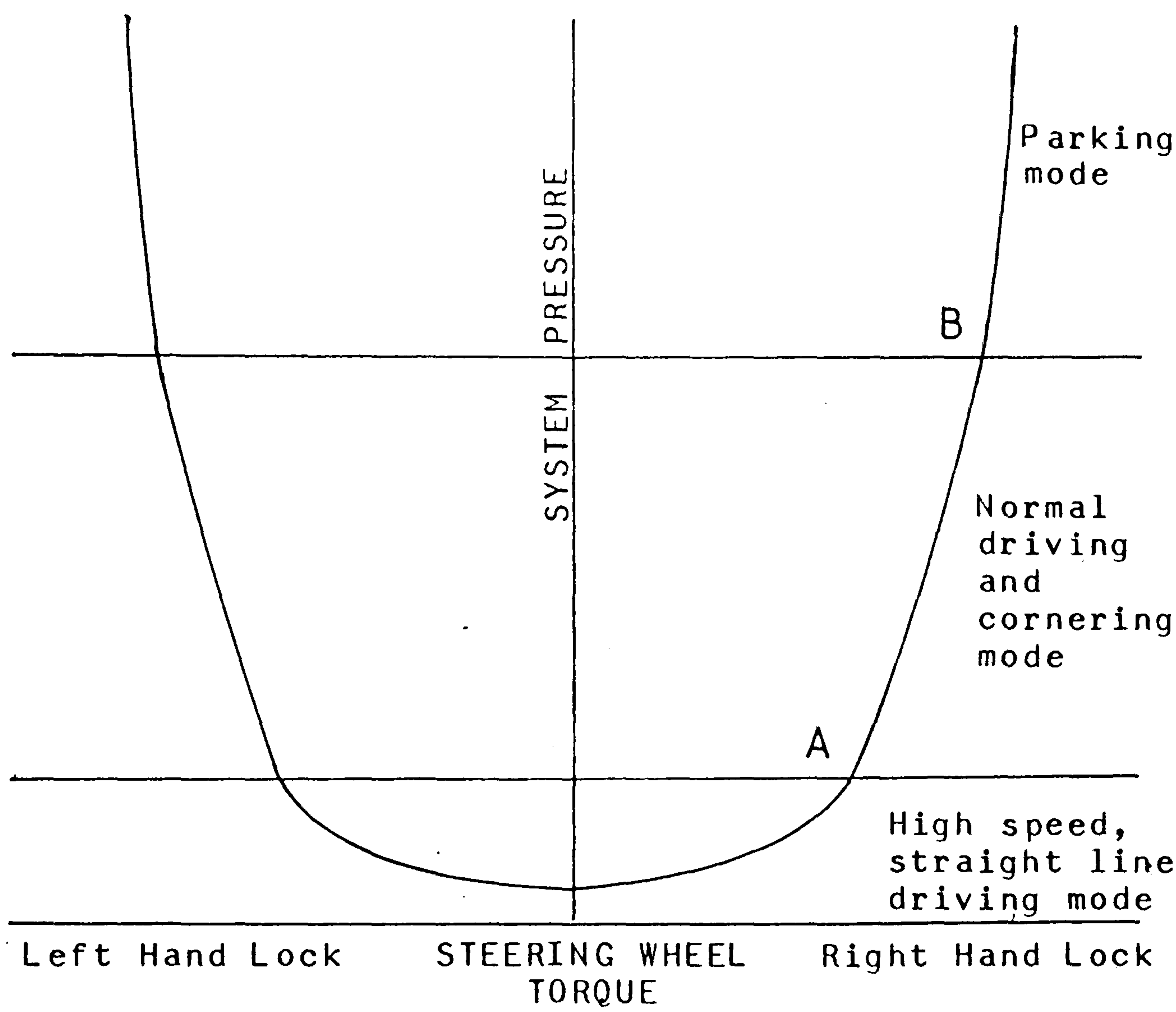

FIGURE 2. Typical steering wheel torque/system pressure curve showing a high speed driving mode, a normal driving and cornering mode and a parking mode.

Three distinct modes of operation are represented by the graph in Figure 2, and these are a high speed, straight line driving mode for which the system pressure remains relatively low; a normal driving and cornering mode for which system pressure rises to a moderate level; and a parking mode for which the system pressure rises steeply to its maximum level. It is generally agreed by vehicle manufacturers who use power assisted steering* that these three modes of operation must be accommodated within the assistance curve. The level of steering wheel torque at which the transition from one mode to another occurs varies, however, with the individual manufacturer's assessment of his customers' preference for relatively 'light' or relatively 'heavy' steering.

The shape of the assistence curve illustrated in Figure 2 is directly determined by the characteristics of the hydraulic fluid control valve mentioned previously. Most important from the drivers' point of view is that the control valve should be designed to provide a smooth transition from one part of the assistance curve to another. Whilst the relationship between steering wheel torque and system pressure is almost linear within each of the operating modes shown in Figure 2, the transition from one mode to the next at points A and B are clearly non-linear. It can be readily appreciated that the rapid increases in the output of the system which occur in relation to small increases in steering wheel torque at these points can make it difficult for the driver to predict how much effort is required to steer the car under these conditions. The designer of power assisted steering systems must pay careful attention, therefore, to the characteristics of the control valve in order to ensure that the adverse

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*The author visited representatives of the Ford Motor Company, Chrysler, Jaguar, Rolls Royce and Aston Martin Lagonda Ltd. to discuss power steering in general terms in the preliminary stages of the present work.

consequences of the non-linearities in the assistance curve are minimized.

1.3.1 A TYPICAL RACK AND PINION POWER ASSISTED STEERING SYSTEM

A detailed discussion of the different types of power assisted steering in use is unnecessary for present purposes, as an understanding of the principles involved in the experimental multi-characteristic steering system to be evaluated in the study can be gained from a discussion of the system upon which it is based. Figure 3 contains a simplified diagram of a typical rack and pinion power assisted steering system which employs a torsion bar and rotary control valve. When the driver applies a force to the steering wheel, the torque is transmitted through the input shaft to the steering gear. Located in the input shaft, however, is a torsion bar. If some resistance to turning the road wheels is encountered, either because of self-aligning torques or because of tyre 'scrub', then as the driver increases his effort to turn the wheel, the torsion bar in the input shaft begins to twist. The twisting of the torsion bar results in relative movement between the inner and outer parts of the control valve which raises the pressure of fluid acting on one side of the hydraulic piston in the steering rack. It is this differential pressure across the rack which assists the driver to turn the front wheels by supplying an added force in the desired direction. Thus, some of the force required to steer the front wheels is supplied directly by the driver, the torque applied at the steering wheel being transmitted through the input shaft to the steering rack. Because of the 'winding up' of the torsion bar which forms part of the input shaft, the control valve meters hydraulic fluid under pressure to the rack thus providing power assistance. As noted previously, the characteristics of power steering, as represented in the assistance curve shown in Figure 2, depend to a large extent upon the design of the control valve, in that the control valve determines the amount of

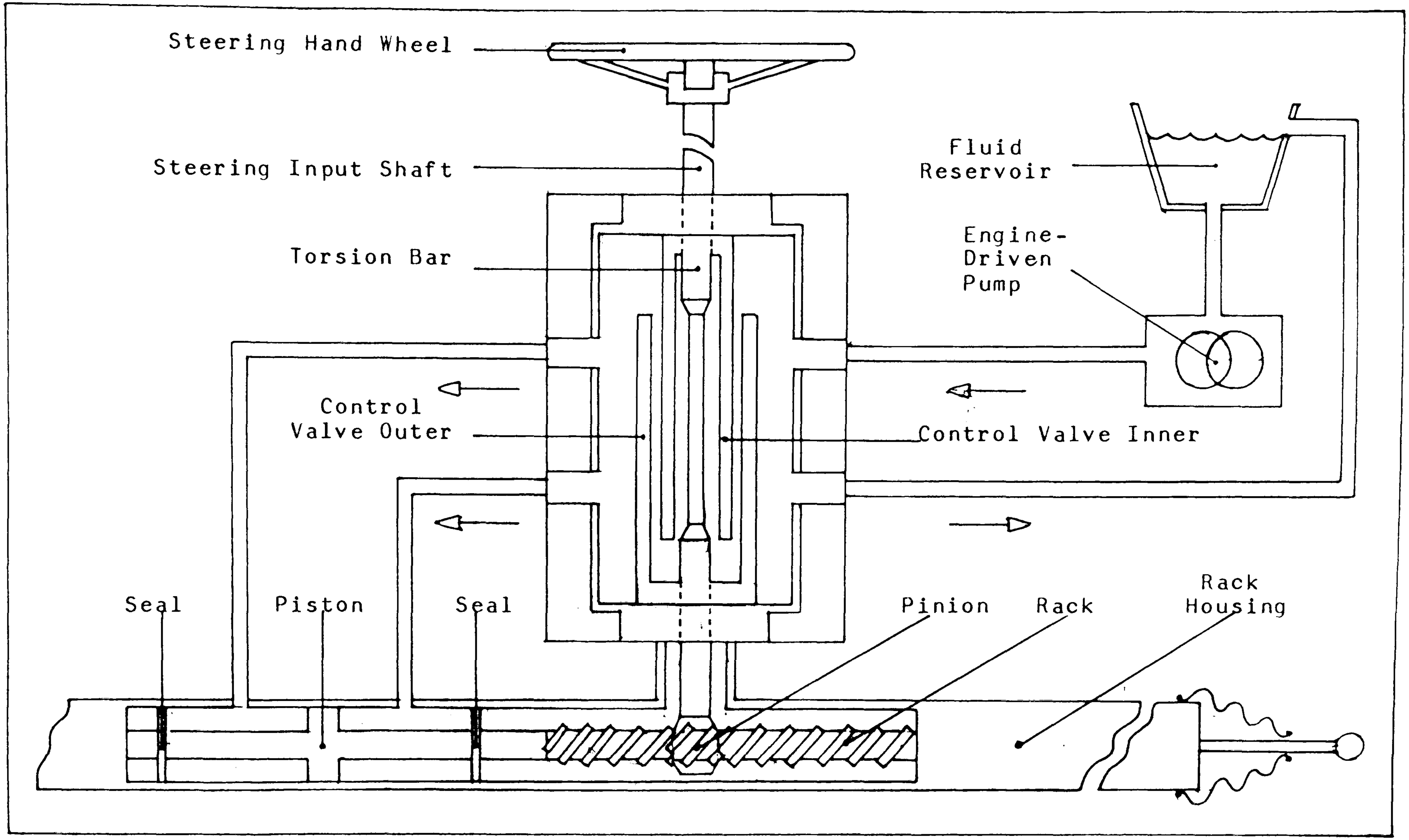

FIGURE 3. <u>Schematic diagram of a typical rack and pinion power assisted steering system.</u>

assistance provided for a given degree of twisting of the torsion bar. The amount of effort required from the driver before power assistance is supplied, however, depends upon the stiffness of the torsion bar. A stiff torsion bar will require considerable torque before it twists and allows the control valve to open, producing a 'heavy' feel to the steering. Conversely, a compliant torsion bar will twist easily, making the steering much lighter in operation. It is a combination of both valve design and torsion bar stiffness, therefore, which completely determines the characteristics of power assisted steering.

Finally, on a purely technical note, the system described above is properly referred to as an 'open-centred' system. This simply means that there is a constant flow of hydraulic fluid through the rack even when no power assistance is being provided. Although this characteristic does not affect the driver greatly, 'open-centred' systems may have an advantage over 'closed-centre' systems in that they tend to provide a more gradual rise and fall in pressure and, therefore, are smoother in operation.

1.4 PROBLEMS ASSOCIATED WITH POWER STEERING

The advantages to be gained from the introduction of power assistance to a car's steering system are fairly obvious. Most important is the reduction of effort required from the driver to steer the car, especially at parking speeds. As mentioned earlier, this can also be achieved by providing a numerically higher steering ratio, but the consequent increase in steering wheel displacement needed to produce large steering angles can make this solution inappropriate. Power assisted steering has the advantage of reducing steering effort whilst maintaining a suitably low steering ratio, providing the driver with light, direct steering. From the driver's point of view, there can be problems with power assisted steering, however, and these are usually attributed to a lack of 'feel'.

1.4.1 THE LACK OF STEERING 'FEEL'

The term 'steering feel' is a rather subjective one, and although commonly used by engineers and others interested in vehicle handling, it is not well defined. In the author's experience, 'feel' generally refers to the force feedback characteristics of the steering system. A steering system with good 'feel' is one which allows the driver to detect changes in the behaviour of the front wheels by means of changes in the torque required to turn the steering wheel. It will be remembered from the general discussion of steering characteristics earlier in the Introduction, that the amount of effort required to turn the steering wheel of a moving car depends to a large extent on the self-aligning torques being generated at the front wheels. The driver is thus able to 'feel' the forces being generated at the front wheels through changes in effort required to turn the steering wheel. In the case of power assisted steering, however, the effort required to steer the car depends only indirectly on the self-aligning torques generated at the front wheels, being directly determined by the hand wheel torque/system pressure characteristics depicted in Figure 2. The power assisted system may suffer a loss of 'feel' over an un-assisted 'manual' system, therefore, in that the amount of effort required to steer the car does not vary directly with the cornering forces and self-aligning torques generated, but depends on the point at which the system is operating on the assistance curve.

For this reason, designers of power assisted steering systems try to ensure that as much as possible of the steering wheel torque/system pressure curve is a straight line, that is to say, the designer seeks to provide a linear relationship between the driver's input and system output, especially over that part of the curve which represents the 'normal driving' mode. In this way, power assisted steering can be made to simulate the force feed-back characteristics of manual steering, providing the driver with a degree of steering 'feel', whilst maintaining a low level of steering effort.

Problems still remain, however, at points A and B on the assistance curve shown in Figure 2, which correspond to changes from one steering mode to another. If the driver is travelling at high speed on a straight road, but is suddenly called upon to make a significant steering manoeuvre, (the system is operating at point 'A' on the curve), only a small increase in steering wheel torque is required to produce a relatively large increase in system pressure and consequently system output. Similarly, the driver making a number of manoeuvres at moderate speeds who is then required to make a more dramatic turn, (point 'B' on the curve), will also experience a sharp rise in power assistance for a relatively small increase in steering wheel torque. Drivers unused to these characteristics of power steering often experience problems when the system is operating at these points, tending to over estimate the effort required to make the desired manoeuvre, and inadvertently steering further than intended. The problem is not a serious one, however, in that drivers soon adapt to changes in the slope of the assistance curve, and the effect tends to be one of having to make small corrections to initial steering movements rather than major recoveries from totally inappropriate steering actions.

A further problem attributed to lack of 'feel' is that encountered when the car is driven onto a slippery surface or when the front wheels lose adhesion for some other reason, (when cornering too fast, for example). The sudden loss of adhesion between the front tyres and the road results in a marked 'lightening' of the steering. As noted previously, this is due to the cornering forces generated by a sliding wheel acting nearer the centre of the contact patch, with a consequent loss of self-aligning torque. It has been suggested that because the steering loads imposed on the driver by power assisted steering tend to be very low in the first place, a further lightening of the steering due to a loss of self-aligning torque would pass unnoticed. In a review article on power assisted steering system design, Curtis (1972) argues that a threshold exists below which drivers cannot detect a change in steering wheel loads, and that some power steering systems require sub-threshold levels of effort from the driver. Whether or not such a load threshold exists, it is certainly the case that a marked reduction in steering effort accompanies loss of adhesion between the front wheels and road in a manually steered car, but that this is much less noticeable in a car with power assisted steering. In a manually steered vehicle, steering loads can be quite high when the driver is cornering hard, so that he is more likely to notice a reduction in effort, which drops to almost zero, when the front wheels begin to slide. The driver of the car with power assisted steering, however, may not notice a change in steering effort if the difference between steering loads before and after the loss of adhesion is very small. Although a noticeable reduction in the required steering effort may provide a sensitive driver with a warning of a low friction road surface, or an indication that he is cornering too hard, it is not known whether ordinary drivers can detect, or respond to, such feedback cues. The importance of a lack of 'feel' in this instance has yet to be demonstrated, therefore.

1.4.2 THE 'SNEEZE FACTOR'

A final problem associated with power assisted steering, and one which has received a measure of attention from manufacturers of steering gear, is sometimes referred to as the 'sneeze factor'.

Earlier in this section, the major advantage of power steering was said to be that it provided "light, direct steering". At high speeds, however, such characteristics are not an unqualified advantage, since any involuntary movement, a sneeze for instance, could cause the driver to steer inadvertently. The 'sneeze factor' can be accommodated by making the steering 'heavier' at speed, so that small forces applied to the wheel accidentally would not be sufficient to produce significant displacement of the wheel. Alternatively, the steering can be made less direct, that is, given a numerically higher steering ratio, so that an inadvertent displacement does not produce a significant steering effect. Some attempts to overcome the problem of the 'sneeze factor' using these two approaches are discussed in the following section.

1.5 APPROACHES TO THE PROBLEMS OF POWER STEERING

Although a number of problems associated with power assisted steering were identified in the previous section, most of the design effort by manufacturers has been aimed at eliminating the 'sneeze factor'. As noted previously, this may be accomplished in one of two ways, either by making the steering 'heavier' at speed, or by providing a numerically higher steering ratio around the straight ahead position. Both methods have been used by manufacturers, the former mainly in Europe and by at least one Japanese manufacturer who exports to Europe, and the latter method mainly in the United States. Underlying the two approaches are separate design philosophies, and, to some extent, these reflect different aspects of the problem.

The driving environment in the United States tends to be very different from that in Europe, and the vehicles which have evolved in these countries also tend to be very different. The American driver is often faced with travelling long distances along relatively straight, relatively fast roads. He has traditionally been offered large, comfortable cars with soft ride, automatic transmission, power steering and power brakes to make long hours of driving effortless. In Europe, drivers tend to cover shorter distances in a more difficult environment, encountering more bends, intersections and congested narrow roads than their American counterparts. The emphasis on car design in Europe has traditionally been put upon producing small cars with relatively high performance engines, good handling characteristics and, typically, with manual transmission and steering. Ironically, with the development of the motorway system in Europe, cars have tended to become larger and more 'Americanised', and with the rising cost of oil, American cars have become smaller and 'Europeanised' in recent years.

Distinct differences remain, however, in the design of steering systems for American and European cars, and these reflect the differing requirements of the American and European driver. Most European manufacturers, for example, have adopted rack and pinion steering, even for power assisted systems, whereas American manufacturers still tend to use systems of the steering gear box type. The steering on American cars also tends to be heavily power assisted which requires very little steering effort from the driver, but lacks 'feel' by European standards. Given that the American driver spends much of his time travelling in a straight line or making right angle turns, however, extremely light steering, even in the absence of marked force feedback characteristics, is presumably adequate for his needs. The European driver on the other hand, who is required to negotiate many curves, roundabouts and such like, is probably better served by a steering system which exhibits more pronounced force feedback characteristics or steering 'feel'. In dealing with the 'sneeze factor', therefore, it is not surprising that American and European manufacturers have adopted different approaches to the problem, and these are discussed below.

1.5.1 VARIABLE RATIO POWER ASSISTED STEERING

Steering ratio was previously defined as an index relating the angular displacement of the steering wheel to the angular displacement of the front (steered) wheels. Thus, a numerically high steering ratio requires a relatively large steering wheel displacement to effect even a small displacement at the front wheels, whilst a numerically low steering ratio requires a relatively small steering wheel displacement to produce a significant displacement of the front wheels. Implicit in this definition of steering ratio is the assumption that the relationship between steering wheel displacement and front wheel angle is fixed. This is not necessarily the case, however, since it is possible to produce a steering system whose steering ratio changes with front wheel angle. In a variable ratio steering system, therefore, the driver may be required to make a large angular displacement of the steering wheel to achieve a minor change in front wheel angle under some circumstances, but a smaller angular displacement of the steering wheel to achieve the same change in front wheel angle under different conditions.

In order to deal with the problem of the 'sneeze factor', therefore, American designers have employed variable ratio power assisted steering which produces a numerically high ratio at small front wheel angles (around the 'straight ahead' position) changing to a numerically low steering ratio at large front wheel angles (at full 'lock'). The overall effect is to produce less direct steering when the driver is travelling at speed on a straight road, so that small steering wheel movements have little effect on the front wheels, and more direct steering when the driver is manoeuvring, so that relatively small wheel displacements produce significant effects at the front wheels. In this way, excessive steering wheel displacements during parking manoeuvres are avoided, whilst the adverse effect of an inadvertant steering input at speed (the 'sneeze factor') is eliminated.

Several variable ratio power steering systems are currently in production in the United States, and one, the Marles-Bendix Variamatic system was, for a time, used by Jaguar and

Rover on some models manufactured in Britain. Both British manufacturers now use rack and pinion fixed ratio gears. In order to investigate drivers' reactions to variable ratio steering, a number of studies have been carried out by the manufacturers and by independent research organisations. These will be reviewed in detail in a later section, but in general, it appears that drivers' steering performance is not adversely affected by variable ratio steering, and in one study, drivers were found to prefer variable ratio to fixed ratio systems.

On a point of theoretical interest, Wohl (1961) has suggested that the ideal steering system would be a velocity dependent variable ratio one. His argument is that a system which produces the same heading change for a given steering wheel displacement irrespective of vehicle speed would simplify the driver's task. Using an electrical analogy, Wohl points out that instead of acting as a high gain amplifier at low speeds, (when large displacements are required to achieve a given heading change), and a low gain amplifier at high speeds, (when relatively small displacements are required to achieve the same heading change), a velocity modulated variable ratio steering system would enable the driver to act as a constant gain amplifier.

Wohl's hypothesis makes intuitive sense, in that, providing the driver with a system whose input/output characteristics are constant should indeed simplify the steering task. Such a system would also eliminate the 'sneeze factor', if it were designed to provide the right degree of sensitivity. Unfortunately, although velocity dependent variable ratio systems have been developed, they are extremely complex, and as far as the author is aware, they have not been used to test Wohl's hypothesis. Furthermore, power assistance may still be required if the steering efforts demanded by such a system were found to be excessive.

1.5.2 ARTIFICIAL 'FEEL' POWER ASSISTED STEERING

In line with the general desire to produce cars with responsive handling characteristics, European manufacturers have sought to introduce artificial 'feel' into their power steering systems. The aim has been to maintain precise, sensitive steering at speed, but to incorporate a 'sneeze factor' by making the level of power assistance speed related. Thus, at low speeds, when steering loads would otherwise be excessive, power assistance is supplied to reduce the effort required from the driver. At higher speeds, when steering loads are typically much lower, the level of power assistance is gradually reduced to avoid excessively light steering and unintentional wheel movements. A relatively low steering ratio may still be used to provide the driver with responsive, direct steering at all times.

Several European manufacturers, and the Japanese company Honda, currently fit power steering systems which incorporate an artificial 'feel' characteristic to cars in volume production*. The European and Japanese systems are very similar in concept, although they differ in the means employed to achieve the desired effect. Thus Citroen, Mercedes, Z.F. and Honda all produce systems which employ hydraulic reaction to progressively inhibit the normal operation of power assistance as speed increases. The Citroen 'varipower' system also provides a self-centring effect to overcome problems associated with its being a closed-centre system. That is to say, one of the system's functions is to return the front wheels to the straight ahead position when the driver releases the steering wheel. Since the systems in production are conceptually similar, only one will be described in detail as an example of how speed sensitive power assistance can be achieved.

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*General Motors also patented such a system as early as 1966 (US patent No. 3433127), although it is not known whether this reached production. As noted previously, American manufacturers have tended to favour variable ratio systems.

This system, which is more fully described in the literature than the others, (see for example, Nishikawa et al 1979) is manufactured by Honda and fitted to their Accord LX model.

The basic steering system used on the Accord is similar to the rack and pinion system described previously, except that, instead of a torsion bar and rotary valve, the Honda steering gear incorporates an axial valve to control the flow of hydraulic fluid to the actuating piston. When the front wheels are steered, an axial thrust is generated at the pinion which is used to create relative movement in an axial control valve supplying fluid under pressure to one side or other of the actuating piston. The pressure differential across the piston, which is mounted coaxially in the steering rack, then assists the driver in turning the road wheels. In incorporating a speed sensitive artificial 'feel', the designer's aim was to "provide a system which gives full power assist at parking speeds with a gradual decrease in assistance with increasing vehicle speed, giving a normal unassisted 'road feel' at highway speeds".

To provide a speed sensitive assistance characteristic, a speed sensor circuit is incorporated into the system. (The main difference between speed sensitive systems lies in the provision and operation of their speed sensing devices.)
The speed sensor circuit in this case consists of a hydraulic motor driven from the speedometer gear, and four hydraulic reaction chambers containing springs located at the axial control valve. As vehicle speed rises, the hydraulic motor in the speed sensor line meters fluid out of the circuit, which allows high pressure fluid from the engine-driven power steering pump into the reaction chambers. At speed then, any axial movement of the control valve when the driver steers is resisted by the hydraulic pressure and the springs in the reaction chambers. This tends to hold the control valve in the 'on centre' or closed position so that, as thevehicle's speed increases, more of the effort required

to steer the car is supplied by the driver and less by the power assisted steering.

To illustrate the effect produced by Honda's speed sensitive variable assistance system, Nishikawa has graphed steering wheel torque against rack load for various simulated vehicle speeds, (measurements were made in the laboratory). Two of these curves, for simulated vehicle speeds of 0 m/s and 17 m/s are shown in Figure 4.

An inspection of Figure 4 shows that, at zero speed, the steering wheel torque required to produce increasing rack loads is relatively low and constant. At 17 m/s however, a positive linear relationship is seen between steering wheel torque and rack load, so that the amount of effort required to turn the wheel is directly proportional to the self-aligning torques being generated at the front wheels.

At parking speeds therefore, the Honda system provides the driver with a high level of power assistance, so that very little effort is needed to steer the car. As speed increases, the level of power assistance is progressively reduced as the speed sensor circuit supplies hydraulic fluid to resist the normal operation of the axial control valve. At moderate speeds, the relationship between steering wheel torque and rack load resembles very closely that of a manual steering system, so that the designer's aim to produce a "normal un-assisted 'road feel' at highway speeds" is achieved.

The authors do not report any attempt to evaluate the operation of their speed sensitive variable assistance system on the road, however, or to test drivers' reactions to the system.

1.5.3 THE CAM GEARS EXPERIMENTAL MULTI-CHARACTERISTIC POWER ASSISTED STEERING SYSTEM

The experimental multi-characteristic power assisted steering system developed by Cam Gears, which is the subject of the

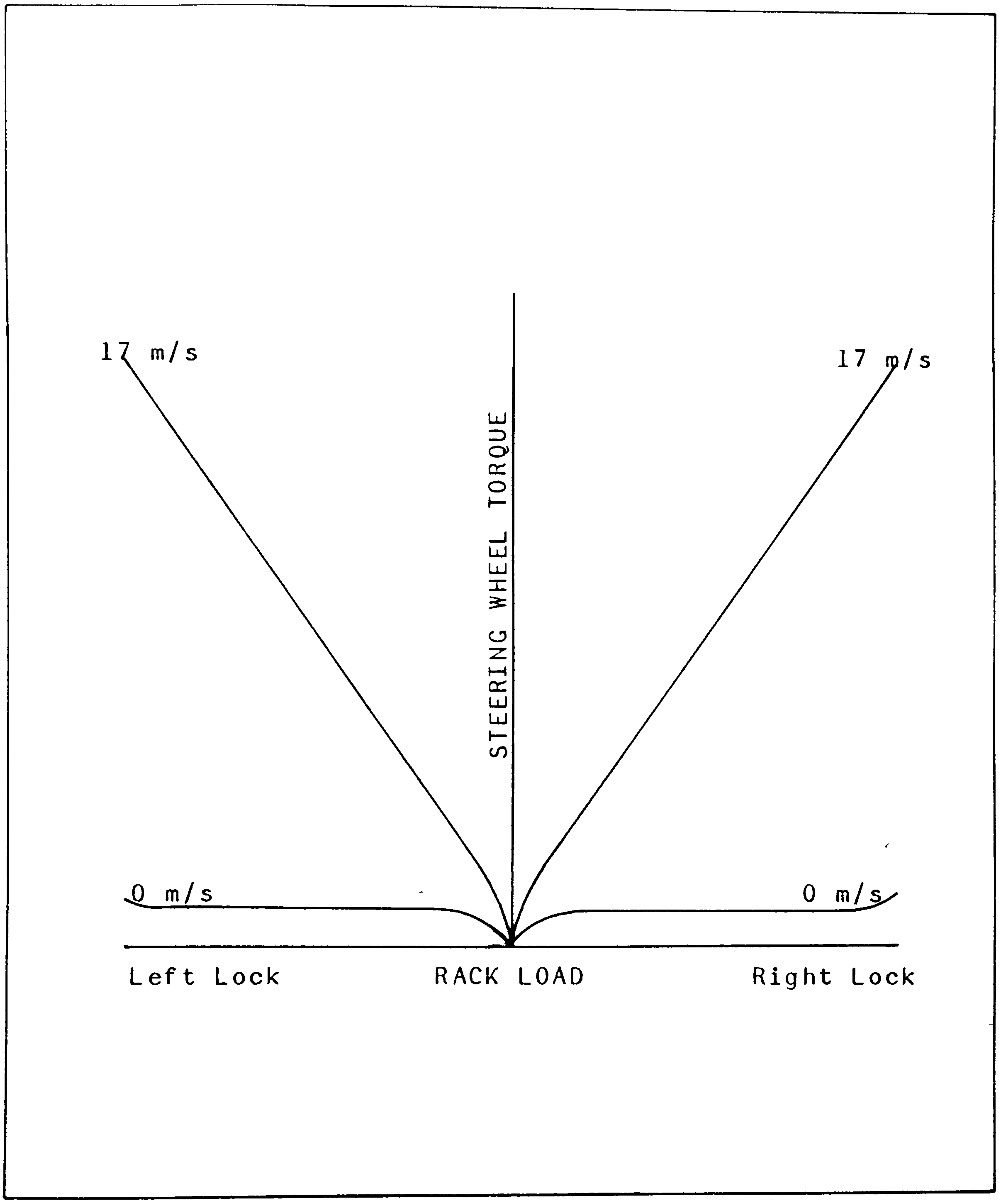

FIGURE 4. Relationship between steering wheel torque and rack load at two simulated vehicle speeds for the Honda Accord speed sensitive variable assistance power steering system. Adapted from Nishikawa et al (1979).

present evaluation, incorporates not only a speed sensitive 'feel' characteristic, but also a number of other artificial 'feel' characteristics which represent different approaches to the problem of the 'sneeze factor' and the lack of 'feel' in normal power assisted steering systems.

The Cam Gears multi-characteristic power assisted steering system is based upon a rack and pinion steering system with torsion bar and rotary control valve like that shown in Figure 3. The experimental system, however, has a modified torsion bar assembly and two additional hydraulic pumps, one driven from the transmission and one electrically powered. A schematic drawing of the experimental system is shown in Figure 5, and the artificial 'feel' characteristics provided by the system are described below.

In the Standard Power Steering mode, the system behaves normally, in that a steering input by the driver is resisted by the road wheels causing the torsion bar to twist, the control valve to operate and an assistive pressure to be generated in the steering rack. When functioning in the experimental modes however, the normal operation of the system is inhibited by the action of the various artificial 'feel' circuits on the modified torsion bar. When hydraulic fluid is supplied under pressure to the two steel balls located in the torsion bar extension tube (see Figure 5), the twisting of the torsion bar is resisted. If sufficient pressure is applied, the effect is to couple the input shaft directly to the pinion, making the torsion bar and control valve inoperative, and preventing any power assistance from being generated. By varying the hydraulic pressure applied to the two balls located in the torsion bar extension tube, the operation of the normal power assisted steering system can be modified to provide a number of different characteristics.

By applying a constant pressure to the torsion bar balls, the steering can be made heavier throughout its range of

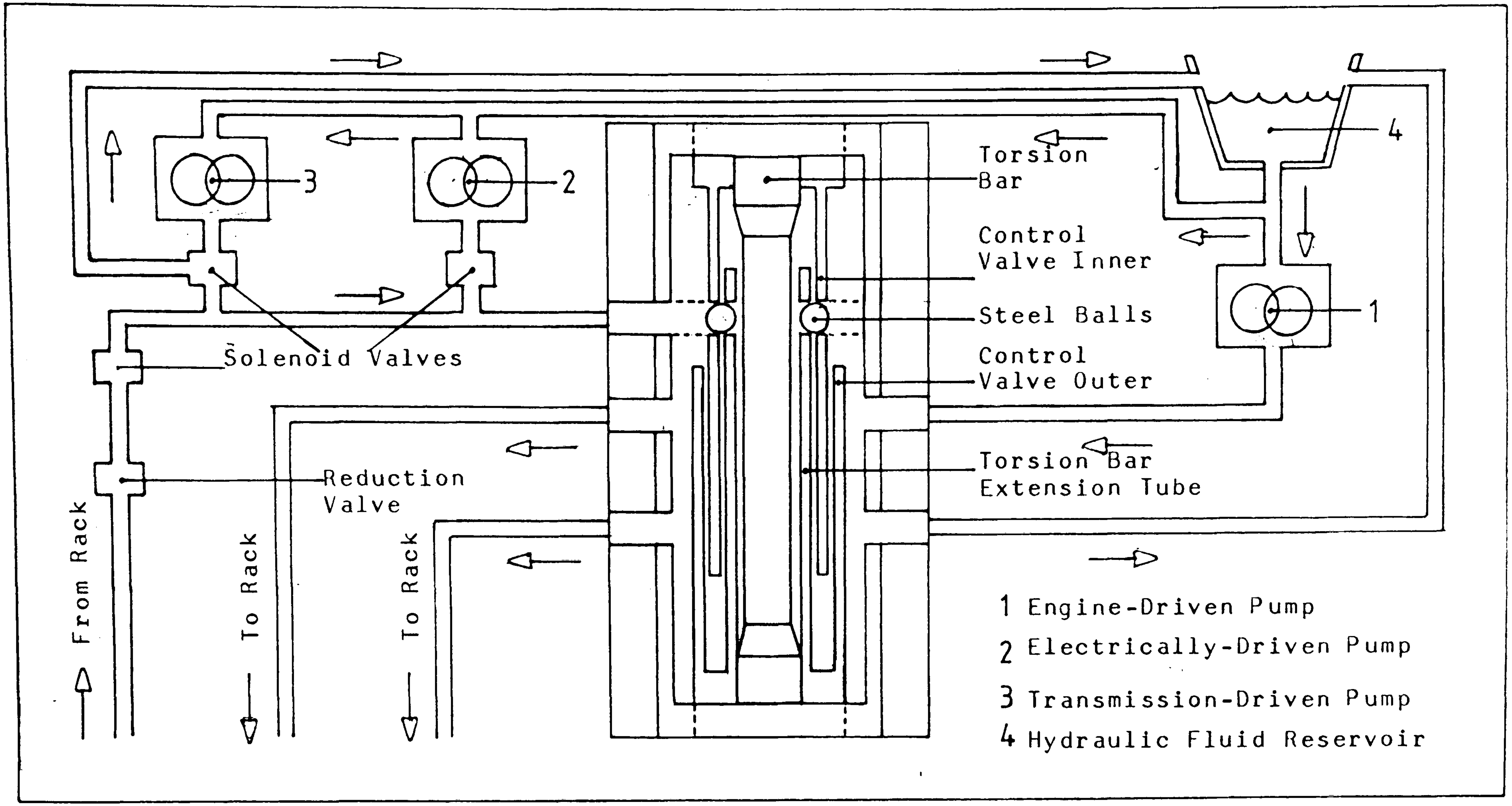

FIGURE 5. Schematic diagram of the Cam Gears experimental multi-characteristic power assisted steering system showing the modified torsion bar assembly and the arrangement of the artificial 'feel' circuits.

operation. In terms of the handwheel torque/system pressure curve depicted in Figure 2, the effect of a constant pressure would be to shift the assistance curve outward from the ordinate, leaving the shape of the curve otherwise unchanged. A greater effort must now be applied to the steering wheel before any power assistance is generated, since the steel balls, which are resisting the wind-up of the torsion bar, must first be dislodged from their place in the extension tube before any movement in the control valve can occur. Because a similar effect could be achieved by fitting a load spring to oppose the twisting of the torsion bar, the two constant pressure conditions provided by the experimental system are called Simulated Fitted Load Spring Heavy, when a pressure of approximately 1.4 MPa is fed to the torsion bar balls, and Simulated Fitted Load Spring Light, when a pressure of approximately 0.7 MPa is fed to the torsion bar from the electrically driven hydraulic pump. The Simulated Fitted Load Spring modes provide a means of testing the hypothesis put forward by Curtis (qv), that a threshold exists below which drivers cannot detect changes in steering loads, since their effect is to increase steering loads whilst leaving the assistance characteristics of the steering otherwise unchanged.

The Cam Gears multi-characteristic system also incorporates two variable assistance 'feel' modes of operation, and these are a Speed Proportional Feel mode, which is similar to the speed sensitive systems described above, and a Conventional Reaction mode, in which the 'feel' characteristics are very similar to those of manual steering systems.

In the Speed Proportional Feel mode, hydraulic fluid is fed to the modified torsion bar assembly from the transmission-driven pump. The effect is again to inhibit the normal operation of the power assisted steering by making it more difficult for the torsion bar to twist, and for the control valve to open, so that more of the effort required to steer the car must be supplied by the driver. Unlike the two Fitted Load Spring modes, in which a constant pressure is applied to the balls located in the torsion bar extension tube, the transmission-driven pump produces a variable pressure and one which is directly proportional to the vehicle's forward speed. In the Speed Proportional Feel mode, therefore, as speed increases and the pressure at the modified torsion bar rises, the level of power assistance decreases. The net result is similar to that of the Honda system, providing maximum power assistance at zero speed and minimum power assistance at high speed. The essential difference between Cam Gears' and Honda's speed sensitive variable assistance systems lies in the means employed to progressively reduce the level of assistance with speed. In the former case, the twisting of the torsion bar is resisted by the steel balls held under pressure and located in the torsion bar extension tube. In the latter case, the movement of an axial control valve is resisted by hydraulic pressure and springs in four reaction chambers. The aim in producing a speed sensitive variable assistance characteristic is the same in both cases, however, that is, to provide the driver with a high level of power assistance at low speeds, when steering efforts would otherwise be very high, and to provide him with progressively less power assistance at higher speeds, when the steering would otherwise become excessively light and the 'sneeze factor' becomes a problem.

In the <u>Conventional Reaction</u> mode of operation, a variable 'feel' effect is produced which is very different from that of the Speed Proportional Feel characteristic just described. The 'feel' signal in the Conventional Reaction mode is supplied by the standard power assisted steering system itself, the hydraulic pressure which is raised in the steering rack during the normal operation of the power steering being fedback to the balls located in the torsion bar extension tube via a reducing valve. Thus, as the driver applies a force to the steering wheel, the torsion bar twists, the control valve opens, and an assistive pressure is generated across the steering rack. By feeding back a proportion of the pressure generated in the rack to the torsion bar balls, further twisting of the torsion bar is resisted, and progressively more of the effort required to steer the car is supplied by the driver. In short, the greater the resistance to turning the road wheels, and, therefore, the more assistance generated by the power steering, the greater the effort required to turn the steering wheel.

The Conventional Reaction System behaves very much like manual steering, therefore, in that the amount of effort required to steer the car depends upon the forces being generated at the front wheels. As mentioned previously, a major criticism of power assisted steering is that it lacks the 'feel' normally associated with the force feedback characteristics of manual steering systems. By providing the driver with an artificial 'feel' which approximates the force feedback characteristics of manual steering, therefore, the Conventional Reaction System directly addresses the problem of lack of 'feel'.

Thus, the characteristics embodied in the Cam Gears experimental steering rack represent an attempt to overcome the problems identified earlier which are associated with power assisted steering. The Speed Proportional Feel characteristic is designed to overcome excessive sensitivity at speed or the 'sneeze factor'. If a threshold exists below which drivers are unable to detect changes in steering loads, then the two Simulated Fitted Load Spring characteristics are available to raise steering loads without changing other aspects of the steering. The Conventional Reaction system which closely resembles manual steering in its force-feedback characteristics, avoids the criticism generally made of power assisted steering that it lacks steering 'feel'. In the 'Standard Power Steering' mode, the Cam Gears' experimental system provides a baseline against which the other characteristics can be evaluated.

1.6 AIMS AND BACKGROUND OF THE PRESENT STUDY

The object of the present study was to make an evaluation of the experimental multi-characteristic power steering system developed by Cam Gears, in order to specify the 'optimal' characteristic for use in future production systems. By 'optimal' is meant that characteristic to which drivers could be said to have responded most favourably during the evaluation process.

For the reasons given in the previous section, it was expected that drivers would react more favourably to the artificial 'feel' characteristics than to the characteristics of the standard power steering, although it was not the intention to test directly the design principles upon which the artificial 'feel' systems were based. Rather, it was the intention of the present study to record drivers' verbal and behavioural responses to each characteristic, to devise criteria by which to select the optimal characteristic on the basis of these observations, and then to relate drivers' reactions to the known design principles of the 'optimal' system.

As far as the author is aware, the present study represents the first attempt to systematically investigate the responses of ordinary drivers to the characteristics of power assisted steering. Work has been carried out on drivers' steering performance in relation to the vehicle's steering ratio, steering force feedback characteristics and in the general area of vehicle handling, and some of the more relevent studies are reviewed below. None of these studies, however, has been concerned with power steering characteristics per se , and all have been rather limited in their scope.

The reasons for this apparent lack of interest in drivers' responses to power steering characteristics are many. In the first place, changes in most aspects of vehicle design and component systems design tend to be evolutionary rather than revolutionary. Small changes from established designs tend to be the order of the day, so that the likelihood of producing a system with serious short-comings is felt to be fairly small. At the same time, manufacturers do employ 'in house' methods to evaluate the acceptability of new designs. In the case of single components or sub-systems, 'acceptability' can often be measured in terms of the component's expected service life, and testing to destruction can be employed as a satisfactory means of determining acceptability. In the case of steering systems, and other sub-systems which affect vehicle handling, the question of acceptability is a more subjective one and not as easily answered. The 'in house' evaluation of vehicle steering for instance, usually takes the form of vehicle handling tests carried out by the company's engineers or specially employed test drivers, who are required to complete appraisal sheets like that shown in Appendix A. Whilst such an evaluation presumably prevents manifestly unsafe or unacceptable systems from being incorporated in production models,it is less than satisfactory for a number of reasons.

The main problem with using special test personnel to evaluate vehicle sub-systems is that their opinions are both biased, being company employees, and limited, since theirs is only one of a number of possible responses and is not necessarily representative of the general driving population. It becomes particularly important to elicit a range of responses when a choice is to be made, on the basis of the evaluation, between alternative systems. If the alternatives to be considered are equally acceptable in terms of reliability, economy, and other production criteria, and each is thought to represent an improvement over previous systems, then it becomes particularly important to evaluate those alternatives from the user's or consumer's point of view.

In the United States, an interest in the extensive evaluation of vehicle systems, partly prompted by Federal legislation, has led the major vehicle manufacturers to set up their own Human Factors research departments. Ford, for example, have a number of psychologists, ergonomists and engineers working at their Safety Research Centre at Dearborn, Michigan who have carried out research into various aspects of driver performance in relation to vehicle design. In one, unpublished, study (Forbes 1978), differences were noted between the path taken by a test vehicle fitted with manual steering and that taken by a test vehicle fitted with power assisted steering when drivers were instructed to make a right angle turn. In the former case, the test vehicle's trajectory produced a shallow entry curve and abrupt exit path. In the latter case, the test vehicle followed a sharp entry curve with a more gradual recovery path. Thus, drivers avoided the high steering efforts normally associated with manual steering by applying their initial steering input gradually, and then allowing the vehicle to recover sharply on exit by taking advantage of the high 'returnability' of the steering to the straight ahead. In the latter case, drivers took advantage of the low steering efforts associated with power steering and made a sharp initial turn followed by a more gradual recovery to the straight ahead position on exit.

Independent research establishments have also become increasingly involved in the investigation of the effects of vehicle characteristics on drivers' performance. Calspan Corporation of Buffalo, New York, and Systems Technology of Hawthorne, California, have carried out several pieces of work under contract to one or other of the motor manufacturers. One such study, carried out for the Ford Motor Company by Calspan, Brayman and Rice (1967), is reviewed below. The work carried out in the automotive field has been heavily influenced by, and follows directly from, studies which sought to evaluate aircraft handling qualities on the basis of pilots' subjective ratings. In many cases, the techniques used by those involved in the evaluation of aircraft handling have been applied directly to the automotive field. As the result of the pioneering work of Leonard Segel and others at Systems Technology, therefore, an extensive body of literature has been built up on many aspects of driver/vehicle handling, including fairly sophisticated mathematical models of driver/vehicle behaviour.

Although some of this work has concerned itself with vehicle steering, steering characteristics were, however, rarely the parameters of primary interest. The driver's ability to steer a vehicle in a specific manoeuvre is often the dependent measure in these studies, but the experimental variables tend to be such vehicle response parameters as vehicle response time, yaw rate, and lateral acceleration gain.

Some studies have been concerned with steering system characteristics, however, and although of only marginal relevance to the present work, serve to place it in context. These studies are reviewed below, therefore.

1.7 A REVIEW OF PREVIOUS RESEARCH ON DRIVERS' RESPONSES TO VEHICLE STEERING CHARACTERISTICS

The steering characteristic which has received most attention in the literature is steering ratio, and this includes the effects of variable ratio steering on drivers' performance.

Two studies conducted at the University of Melbourne, Hoffman and Joubert (1966, 1968), explored the effects of a number of vehicle response parameters on drivers' steering performance, among them steering gear ratio and steering torque. In the first study, Hoffman and Joubert (1966), 12 subjects drove a circular course marked out by cones at a fixed speed of approximately 29 k/h, with and without the power assisted steering in operation. Although this represented a 5-fold increase in steering torque levels between the two conditions, no significant difference was noted in the number of cones hit by subjects. In the same experiment, the vehicle's steering ratio was also changed, by means of a gearbox placed in the steering column, to one of three values, 20:1, 24:1, or 28:1, and in addition to the number of cones hit, vehicle yaw rate at various points was also recorded. No significant differences were found between the steering ratios for the number of cones hit or yaw rate fluctuations.

The second study, Hoffman and Joubert (1968), was carried out to determine drivers' sensitivity to various vehicle characteristics including steering ratio. The authors used two methods of determining just noticeable differences (j.n.d.'s) and five ratio settings, 20:1, 22:1, 24:1, 28:1 and 30:1. No significant differences were found between the magnitude of j.n.d.'s at a constant speed of 48 k/h but at different inter-stimulus intervals for five drivers. There were significant differences in the magnitude of j.n.d.'s at different speeds however, drivers being more sensitive to steering ratio changes at 48 k/h.

These studies suggest that, although drivers are relatively sensitive to steering ratio in terms of their ability to detect ratio changes, drivers' performance on a fairly simple steering task is not greatly affected by changes of ratio between 20:1 and 28:1.

Brayman and Rice (1967), in the experiment referred to briefly above, carried out an evaluation of the 'wrist-twist' steering concept for the Ford Motor Company (USA). Drivers' subjective evaluations of three vehicles were compared, one a standard power assisted vehicle with 24:1 ratio steering, one a Marles-Bendix Varamatic power steered vehicle, and the third a vehicle with Varamatic power steering and 'wrist-twist' instead of the conventional steering wheel. (The 'wrist-twist' concept involved a pair of 10.5 cm diameter wheels with a rim projection containing a thumb hole, which were mounted shoulder width apart on a yoke at the end of the steering column). Although no figures are quoted by the authors for the Varamatic steering gear, it would appear from the graphs of steering wheel angle versus front wheel angle provided in their report, that the steering ratio varied from approximately 24:1 to 11:1. Six subjects performed

16 "abrupt" lane-change manoeuvres in each car, and were asked to rate the vehicles on a 6 point scale in terms of their "directional stability", "manoeuvrability", "recovery", "control", "precision" and "feedback". In addition, manoeuvre time, steering wheel angular input and front wheel angle were recorded. Further data were collected from 3 "experienced" drivers who drove each of the vehicles in a longer evaluation exercise which included expressway driving, commuter trips, rapid passing and parking. These drivers used the revised Harper-Cooper rating scale, originally developed in aircraft handling evaluations, on which points 1 to 6 are considered 'acceptable' and points 7 to 10 'unacceptable'.

No statistically significant differences were found between the three vehicles in terms of manoeuvre time, steering wheel angular input or front wheel angle on the lane-change manoeuvre, (data used in the analysis were recorded at vehicle speeds of 48 k/h). No statistical analysis was made of subjects' questionnaire responses although the authors report more favourable mean ratings for the two variable ratio cars. Subjects thought that their performance on the lane-change manoeuvre was better in the 'wrist-twist' car than the Varamatic car, and worst on the standard power steering car. The Harper-Cooper ratings of the three drivers who drove the cars over a longer period suggest that they generally preferred the two variable ratio cars to the standard car, with no particular preference for one over the other of the variable ratio vehicles.

A more extensive and systematic investigation into the effects on drivers' steering performance of both variable and fixed ratio gears was made by Olson and Thompson (1970). The fixed ratio gears tested were 11:1, 13.5:1, and 16:1, and the variable ratio gears were 16-12.2:1, and 16-8:1. Subjects in the study were all General Motors employees from their research and development establishment at Warren, Michigan.

In the first of five separate parts of the study, 30 subjects performed a number of manoeuvres and rated the experimental cars in terms of their "overall steering characteristics", "confidence in directional control" and "ease of tight manoeuvreing". In the second phase of the experiment, 16 subjects were timed while they carried out a parallel parking manoeuvre 10 times with each car, and rated the cars from "best" to "worst". The third phase consisted of low speed manoeuvreing on an egg-shaped course marked by traffic cones. Sixteen subjects made 10 circuits of the course, 5 times in each direction, and the dependent measure was the number of cones hit. Vehicle speeds in this section were typically very low, approximately 11 k/h, and subjects again rank ordered the test vehicles in terms of ease of manoeuvreing. For the fourth and fifth phases of the study, two lane-change manoeuvres were devised which would provide 5 m/s^2 lateral acceleration at 40 k/h and 97 k/h respectively. Twelve subjects drove each car 10 times through the manoeuvres, and the number of cones hit was taken as the dependent variable. Not all the fixed and variable ratio gears were represented in all phases of the study.

In the first part of the study, subjects rated the 16-8:1 variable ratio gear as significantly poorer than both the 16-12.2:1 variable ratio and the 16:1 fixed ratio gear, which were not found to be significantly different from each other. In the parallel parking manoeuvres, parking times were significantly shorter for the 16-12.2:1 variable ratio gear than for the linear gears tested, and parking times for the 16-8:1 variable ratio steering were shorter than those for the 16:1 linear gear. The 16-12.2:1 variable ratio gear was also rated more highly than the other steering ratios in the second phase of the experiment. In the third phase of the experiment, no significant differences were found between gears in terms of the number of cones hit or subjective ratings during low speed manoeuvreing. No significant differences in the number of cones hit were found for any of the variable or fixed ratio gears in the fourth, (low speed, high lateral acceleration) or the fifth, (high speed, high lateral acceleration) phases. The authors conclude that variable ratio gears are of some benefit to drivers when gross steering movements are made, for example when parking, but do not appear to affect vehicle control under a variety of other driving conditions. The subjective ratings of the gears indicate a dislike of the more extreme 16-8:1 variable ratio gear.

Although Olsen and Thompson used a variety of different manoeuvres at low and relatively high speeds, they did not attempt to evaluate drivers' performance in high speed steady state conditions. Thus, while it seems likely that variable ratio steering improves low speed manoeuvreability, in that parking times were reduced, the effects of variable ratio steering on high speed straight line driving were not investigated, even though one of the aims of variable ratio steering is to reduce steering sensitivity at speed. The authors themselves also suggest that a sudden large-scale evasive manoeuvre, after prolonged driving requiring only minor steering inputs, should be a feature of future studies, in order to see whether the ratio changes encountered during large steering inputs adversely affect drivers' steering performance.

An earlier piece of work from the Cornell Aeronautical Laboratory, which has more direct relevance to the present study, investigated the effects of steering force gradient on drivers' subjective evaluations. Using a vehicle in which artificial steering torques could be generated in relation to the vehicle's yaw rate or lateral acceleration, Segel (1964) set out to test the hypothesis that steering force gradient, already found to be an important parameter in pilots' ratings of aircraft handling, would also be important in automobile drivers' subjective evaluations of vehicle handling. (Steering force gradient in this case being the effort applied at the steering wheel per unit lateral acceleration of the vehicle, defined in terms of Nm/g where $g = 9.81\ m/s^2$). Five drivers, all familiar with aircraft handling evaluation techniques, drove the test vehicle in steady state turns involving .2g lateral acceleration, and in a "fast passing" manoeuvre. Subjects then responded to questions concerning the precision and ease of making the turn, the force required to make the turn, the size of the steering input required in making the turn, the vehicle's response in the passing manoeuvre, the precision and ease with which the passing manoeuvre was made, the initial force required and the size of the initial control movements made in the passing manoeuvre.

The data from this experiment were not subjected to statistical analysis, but on the basis of drivers' evaluations the author made the following conclusions:

1) Too light a force gradient mades it difficult to precisely position the steering wheel, with the result that drivers may undershoot or overshoot the desired path when making a turn.

2) Steering wheel displacement appears to increase as the force gradient decreases, i.e., drivers became more aware of wheel displacement at lower force gradients.

3) There is an optimum force gradient below which the straight ahead position is poorly defined, and above which the return of the steering wheel to the straight ahead position becomes too rapid.

4) The precision of the steady state turn is less influenced by force level than the precision of the passing manoeuvre. The size of the wheel displacement is also less important in steady state than transient manoeuvres.

5) Damping of the steering is also an important factor in drivers' ratings.

Segel tentatively suggests that a force gradient of 25 Nm/g might be considered optimum on the basis of the limited data acquired.

Although the above study was exploratory in nature, and the small number of drivers used comprised a very biased sample of the driving population, at least one point of importance emerges from the study. Segel notes that, whilst force feedback to the driver aided him in completing the assigned manoeuvres, subjects were still able to steer the car satisfactorily around the course in the absence of any steering 'feel' at all. In other words, although drivers' evaluations were most favourable with a steering force gradient of 25 Nm/g, they could still steer the car satisfactorily using the steering wheel simply as a position control.

In concluding this very brief review of work which investigates the effects of steering characteristics on drivers' performance, it can be seen that very little has been done to systematically and comprehensively evaluate steering system characteristics in terms of driver responses. In only one study, Brayman and Rice (1967), were subjects allowed to drive experimental vehicles on public roads, most studies confining their attention to drivers' performance in restricted, and relatively simple, off-road manoeuvres.

The results of those studies which took as a dependent variable the number of cones hit by subjects suggest that this is not a particularly sensitive measure of performance. Drivers were able to adapt sufficiently to steering systems with widely differing ratios or force feedback characteristics without evidencing a performance decrement in terms of the number of marker cones hit. Indeed, a feature of many vehicle handling studies is the observation that drivers are able to adapt to even severely degraded systems with no apparent change in performance.

In contrast to what might be called the objective data such as the number of cones hit by drivers, the subjective data, i.e. drivers' ratings of experimental vehicles, generally were sensitive to differences in steering characteristics. Unfortunately, in two of the three studies which asked for drivers' subjective evaluations, no statistical analysis of the data was made, (Brayman and Rice 1967, and Segel 1964), and in only one study, (Brayman and Rice 1967), was the questionnaire administered to subjects actually given in the report. Although drivers' subjective evaluations would appear to be a potentially valuable source of information, the results of the studies reviewed above should be treated with caution.

1.8 METHODOLOGICAL CONSIDERATIONS

Since the characteristics of the Cam Gears experimental steering system were diverse in nature, and since an evaluation of this type had not been undertaken before, it was deemed desirable to 'cast the net' as widely as possible when considering which aspects of drivers' performance should be included in the study. The general approach was, therefore, to involve a large number of subjects in the evaluation, and to record as much data as possible from a variety of sources. Furthermore, a laboratory study, in which a number of parameters would be varied over a limited range of values in a simulated vehicle, was clearly not an appropriate approach for the purposes of the present study. Instead it was thought necessary to allow subjects to drive an experimental vehicle fitted with the multi-characteristic system for fairly long periods in the real world, so that their verbal and behavioural responses to a range of normal driving conditions could be recorded. In addition, a relatively large sample of both male and female drivers of all ages and levels of experience would be required to make the results of the study as generalizable as possible.

Having established the general methodological principles upon which to base the study, a number of aspects of its design and implementation were then considered in more detail.

1.8.1 PILOT STUDY

The most convenient way to elicit and to record subjects' verbal responses is, of course, to use a questionnaire of some kind. However, it is also of vital importance to make the content of the questionnaire meaningful for the intended subject population. Since it was not known which questions about power steering characteristics would make sense to drivers who may or may not have driven with power steering before, it was anticipated that considerable effort would need to be expended in finding out what concepts ordinary drivers might use in describing power assisted steering.

In order to provide this information, it was decided to carry out a pilot study in which drivers would be encouraged to make as many comments as they wished whilst driving a power steered vehicle over a variety of different roads on a test route. Drivers' comments, made freely under these relatively relaxed and informal 'test' conditions would then be used as a basis of the evaluation questionnaire. The pilot study is described in detail in the Method section.

1.8.2 'FAMILIARIZATION' RUN

Previous experience in the field of driver behaviour research suggested that drivers require at least an hour to become reasonably familiar with a strange car. It was, therefore, decided that subjects would be allowed a 'familiarization' run on the test route prior to the experimental run. The test route would be designed to take approximately an hour to drive, and would be composed of town driving, trunk road and rural 'A' class roads, and a motorway section. On the first, familiarization, drive all subjects would use the standard power steering so that, besides allowing drivers to become used to the car, the experimental procedure and the test situation, data would also be available to provide an evaluation of the standard power steering characteristics. On both the familiarization and the experimental road drive, an observer would accompany subjects in order to explain the route to be followed, and to record whatever data was deemed appropriate. Of interest would be driving variables such as speed, lane-position, steering behaviour on bends and when overtaking, the subjects' steering technique and so on. These would be recorded on a specially prepared observation sheet.

1.8.3 RECORDING DRIVERS' STEERING BEHAVIOUR

Since the study primarily concerned the evaluation of the vehicle's steering, it was also thought to be appropriate to record the driver's steering inputs. Unfortunately, a continuous record of steering wheel position for such a long drive would be both difficult to record, and time consuming to interpret. Because steering input was to be only one of many variables recorded, and because the relative importance of steering input could not be estimated on an a priori basis, the sizeable research effort required to provide a continuous record of steering activity was not felt to be justified.

A limited amount of information about steering inputs can be gained fairly easily, however, from a record of steering reversals, that is, the number of times the steering wheel is moved to and fro across a given angle. Steering reversals of small and large degree are relatively easily detected and recorded. Furthermore, steering reversals are known to be affected by such variables as the nature of the steering task, the type of road over which subjects are driving, and a number of driver variables. Moreover, steering reversals have been found to be unaffected by the type of steering normally used by drivers. The findings of a representative selection of studies in which steering reversals have been used as a measure of driver performance are described in the following paragraphs.

The earliest use of steering reversals in driver behaviour research is usually attributed to Greenshields and Platt, (see, for example, Greenshields 1963, Platt 1963, Greenshields and Platt 1967), who recorded several driver input and vehicle output variables to compare drivers with different accident and violation records. These authors found that they could discriminate between different groups of drivers on the basis of five variables including steering wheel reversals. Safren, Cohen and Schlesinger (1970), found that while steering wheel reversals were a reliable measure of drivers' steering performance, in that they did not vary over time, there was no significant difference between experienced and inexperienced drivers' steering reversals as they negotiated a mile-long, U-shaped, driving course. Johns and Bundy (1974), found that subjects' steering wheel reversal rates were consistent over time, and further, that fine steering wheel reversals were unaffected by road type, whereas coarse steering wheel reversal rates were different over different sections of the route. "Fine" steering reversals were defined in this study as wheel displacements exceeding ¼ inch (6 mm) and "coarse" steering reversals defined as wheel displacements of 1¼ inches (30 mm). The authors suggest that fine steering wheel reversals tend to reflect individual differences amongst drivers, but that coarse steering wheel reversals reflect changing road conditions.

Maclean and Hoffman (1975) reviewed previous work in which steering reversals had been used to measure steering performance, and concluded that frequency characteristics, i.e. reversal rates, provide a measure of steering task difficulty rather than steering performance. They further suggested that the difficulty of a steering task depends not only on the nature of the task, for example, lane width or the speed at which the task is carried out, but also on the degree of error tolerated by the driver. The authors argue, therefore, that differences in reversal rates may reflect either task difficulty or the driver's error criterion. Although this observation is undoubtedly a valid one, no evidence is produced which indicates that drivers' error criteria are dependent upon the nature of the task, so that the distinction made between task-imposed and self-imposed difficulty is a rather artificial one.

A more important point made by Maclean and Hoffman is that the gap size across which reversals are measured will have an important bearing on the interpretation of results of steering reversals data. Peak reversal rates in a study reported by these authors correlated most highly with reversal gaps of between .035 and .175 rad depending upon the nature of the task performed. Of equal importance to the interpretation of steering reversals data, however, is the steering ratio and the steering response characteristics of the test vehicle, neither of which are mentioned by Maclean and Hoffman.

In a study designed to determine how two different kinds of highway affected drivers' control responses under normal driving conditions, Soliday and Allen (1972) found no differences in control use, including fine steering reversals, between a group of women drivers used to manual steering and a group of women drivers used to power assisted steering. Fine steering reversals were defined in terms of a 2^{o} (.035 rad) displacement of the steering wheel, and the experimental car in this study was equipped with power assisted steering. The authors did find large differences on all control variables between the two types of highway on which subjects drove, with more control use occuring in rural highway driving than interstate highway driving.

Finally, in a more recent study, Greensmith (1981) has investigated the effects of male and female drivers' accident record and exposure on a number of vehicle control use and other variables including fine and coarse steering reversals. Fine steering reversals were defined in the Greensmith study as an angular displacement of $\pm 2^{o}$ (.035 rad), and coarse steering reversals as an angular displacement of $\pm 14^{o}$ (.24 rad). Discriminant analysis and factor analysis were successfully used by Greensmith to characterise groups of drivers in terms of these driving variables. Accident free drivers were found to make many adjustments to their speed, both up and down, to generate higher levels of lateral acceleration when cornering, and to make more coarse steering reversals than accident-involved drivers. Accident-involved drivers, on the other hand, were found to drive faster when they had the opportunity, made more fine steering reversals, passed other vehicles more frequently, and made more accelerator applications than non-accident drivers. Greensmith was also able to distinguish between male and female drivers on the basis of combinations of the driving variables, and of interest here is that female drivers tended to make more fine steering reversals than male drivers. In a test-retest measure of these variables' reliability, fine steering reversals were found to be one of the least consistent measures of driving performance. This latter finding contrasts with the results of the Safren, Cohen and Schlesinger study mentioned previously which suggested that steering reversals were a reliable measure of drivers' steering performance, in that they did not vary over time.

The results of these studies clearly indicate that steering reversals provide a useful measure of steering performance in a variety of driving situations. Of particular relevence to the present study is the finding that the number of fine steering reversals made by the driver are unaffected by the type of steering normally used, and the finding that steering reversals may be interpreted as a measure of steering task difficulty. It was decided, therefore, to include fine and coarse steering wheel reversals as dependent measures in the present study.

The device to be employed for recording steering reversals was obtained from the same source as those used in the studies referred to above, with the exception of Maclean and Hoffman (1975) who extracted reversals data from more comprehensive continuous steering wheel position records. The reversal gaps measured in previous studies were not equivalent, however, which makes direct comparison of results difficult. A further complication arises from the fact that the steering ratio of the experimental vehicle in studies of this type will also have an effect on the interpretation of results, in that the lower the vehicle's steering ratio, the greater the heading change implied by a steering wheel reversal of a given magnitude.

In the present study, both steering ratio and the angle of rotation of the steering wheel for fine and coarse reversals were measured in order to facilitate the interpretation of steering reversals data. The test vehicle's steering ratio was estimated by recording front wheel angle for each of a number of steering wheel angles from full left lock to full right lock, and plotting these values on a graph. (Front wheel angles were measured by mounting the wheels on radius plates. The static nature of these measurements ignores any compliance effects due to forces generated by contact between moving tyres and road.)

Having established that the test vehicle's steering ratio was in the region of 18:1, steering wheel angles corresponding to a 'fine' and a 'coarse' steering reversal recorded by the device were also measured, again with the vehicle stationary, its front wheels mounted on radius plates. Fine steering reversals were found to correspond to wheel movements of $\pm$ .044 rad, and coarse steering reversals to wheel movements of $\pm$ .244 rad. The implication of these measurements is that fine steering reversals will not result in vehicle heading changes, but that a small heading change is likely to result from a coarse steering reversal. Previous studies have employed reversal gaps similar to those recorded for the present study, and if it is assumed that the steering ratios of the experimental vehicles used were in the region of 20:1 to 24:1, (a reasonable assumption since these were all American cars), then the meaning of 'fine' and 'coarse' steering reversals is likely to be roughly comparable between this and previous work.

1.8.4 TEST-TRACK DRIVING TASK

In addition to observing subjects' driving on a variety of public roads, it was also decided to require subjects to complete specific driving manoeuvres on a test-track. By asking subjects to perform a number of highly constrained driving tasks it was felt that individual differences in driving technique would be minimized and differences in performance due to steering characteristics would be maximized.

The manoeuvres incorporated in the test-track driving task were designed to be representative of normal driving conditions, but at the same time to constrain drivers to follow a particular path delineated by traffic cones. Thus, a low speed lane-keeping task, a small radius 'roundabout' manoeuvre, a garage parking manoeuvre involving forward and reverse parking, a lane-change manoeuvre and a 'slalom' manoeuvre were linked in a continuous test circuit.

The following dependent measures were chosen to quantify subjects' performance on the test-track; the time taken to complete each of the manoeuvres, the number of fine and coarse steering reversals made during each manoeuvre, and the number of marker cones hit by subjects. In the event that subjects' performance on these primary task measures was found to be the same irrespective of the power steering characteristic in use, it was decided to include a subsidiary task in the hope that any differences in the mental load imposed on drivers by the steering systems would become apparent.

1.8.5 THE TEST-TRACK SUBSIDIARY TASK

The use of subsidiary tasks in driving research has a fairly long and chequered history. The rationale underlying their use is that where no errors occur in the performance of a primary task, for example drivers carrying out manoeuvres on the test area do not collide with the marker cones, a subsidiary loading task may be added to occupy subjects' spare mental capacity. If the primary task then becomes more difficult, for instance if drivers are given an 'inferior' steering system, subjects will still be able to perform the primary task adequately, but will be forced to shed the secondary task or to make errors in its performance indicating a reduction in 'spare' mental capacity.

The problem with subsidiary tasks however, is that they may sometimes disrupt performance of the primary task, and only when the primary task remains error-free can the subsidiary task performance be taken as an index of spare mental capacity.

A series of papers by Brown (1965), Brown and Poulton (1961) and Brown, Simmonds and Tickner (1967), illustrate the use of subsidiary tasks in a driving context. The first study, by Brown and Poulton, used two groups of drivers, "advanced" and "average", and two subsidiary tasks, one an auditory task in which subjects were to detect a new digit embedded in a group of digits, and the other a mental addition task which involved the summation of three digits. The aim of the study was to assess differences in mental load during driving in a residential area and driving in a shopping area, the assumption being that driving in a heavily trafficked shopping area would be more demanding. Both groups of subjects performed with and without the subsidiary task so that any influence of the subsidiary task on the primary (driving) task could be detected. For both groups of subjects, the percentage of errors in the subsidiary task were found to be greater when subjects drove in shopping areas than when they drove in residential areas. Because the subsidiary tasks were always given on the second circuit of the route however, possible effects of the subsidiary task on the primary task were confounded with familiarization with the car. Thus the increased use of accelerator noted for one of the experimental groups may have been the result of responding to the subsidiary task or due to familiarization with the car. No difference in drivers' average speeds was found between the first and second circuits however.

Brown (1965) compared two subsidiary tasks on their ability to measure the effects of fatigue in car driving. It was expected that drivers would draw on their 'reserve capacity' during a long period of driving in order to offset the effects of fatigue and maintain a high level of performance. The inclusion of the subsidiary task would serve to 'use up' this reserve capacity so that errors in the subsidiary task would increase as fatigue built up. The two subsidiary tasks used were an auditory "attention" task, in which subjects were to detect odd-even-odd sequences in randomly presented digits, and a "memory" task in which one letter in a series of ten was repeated and the subject was to name the letter at the end of the sequence. Subjects were police drivers who drove an instrumented car over a 3.5 Km route before and after an 8 hour shift. It was found that neither subsidiary task appeared to affect control use in the driving task, although a slight decrease in driving speed was observed when the subsidiary tasks were given. Contrary to expectation, drivers performed better on the subsidiary task, i.e., made fewer errors, when tested at the end of their shift than they did when tested before starting the shift, and this was especially noticeable in the case of the auditory task.

A possible explanation for these findings is that prolonged driving leads to greater automatization of control skill so that more, instead of less, spare mental capacity becomes available. In order to test this hypothesis, Brown et al (1967) asked subjects to respond to the subsidiary task at intervals throughout 12 hours of continuous driving. Two subsidiary tasks were used in this experiment, the detection of a dim light source presented simultaneously in the interior and exterior mirrors of the car, and an "interval production task" in which the subject responded at a demonstrated rate by calling out 'Ta'. Brown et al found that performance on the vigilance task improved with prolonged driving, although no differences were seen in control use or in the interval production rates.

Although the use of subsidiary tasks in the above studies were largely successful, in that they did not appear to significantly interfere with the primary (driving) task, this has not always been the case in other areas of research. In an excellent review article on the use of subsidiary taks, Rolfe (1971) notes that in many instances, despite instructions to the contrary, subjects do allow the subsidiary task to depress their performance on the primary task, although the effect may not be noticed because primary task performance measures were relatively insensitive. In conclusion, Rolfe suggests that,

> "the secondary task is no substitute for competent and comprehensive measurement of primary task performance. The technique should always be looked upon as a means of gathering additional information rather than as an easy way of gathering primary information."

It was decided to include a subsidiary task on alternate trials of the planned test-track sessions in the present study to provide "additional information" in the sense used by Rolfe. The task designed was a visual one, to make it compatible with the largely visual demands of the driving task, and it was designed to be self-paced, so that the number of responses rather than the number of errors in the task would be taken as an indication of spare mental capacity. It was also felt that by making the subsidiary task self-paced, subjects could easily drop the subsidiary task when the demands of the primary task increased. By administering the subsidiary task on half of the test-track trials, it would be possible to compare primary task measures on those trials in which subjects responded to the subsidiary task and those trials in which they did not, so that any effect of the subsidiary task on the primary task could be detected.

1.8.6 STATISTICAL ANALYSIS

Finally, the implications of the method of implementing the study were considered from the point of view of the statistical analysis of the data.

In the early stages of planning the experiment, a repeated measures analysis of variance design was considered. Repeated measures designs have the advantage of minimizing extraneous variance due to individual differences, and, as a wide variability is associated with most aspects of driver performance, this was felt to be an important feature of the design. Unfortunately, two problems with the use of repeated measures immediately became apparent. These concerned the number of replications required, and possible learning effects.

It will be recalled that the experimental steering system to be evaluated incorporated five separate steering characteristics. For each subject to evaluate each characteristic, however, something like five hours driving, five questionnaires and five test-track sessions would be involved, and this was felt to be too much to ask of subjects, even if spread over a number of sessions. Consideration was therefore given to reducing the number of characteristics evaluated by each subject to two or perhaps three, which it was felt would enable the evaluations to be made in a single session and without demanding too much of subjects. In addition, it was clear that significant learning effects would occur over repeated evaluations, especially on the test-track manoeuvres, so that it would be necessary to balance the design with respect to both order and sequence. Reference was, therefore, made to Winer (1962) in an effort to find a suitable incomplete blocks design balanced for order and sequence. Unfortunately, no suitable design was found which had been worked out for the appropriate number of groups, size of block and which was fully balanced with respect to order and sequence. Incomplete blocks designsalso have a slight disadvantage, in that some information is lost on the higher order interactions which, in the case of the present work, could have been important. It was decided, therefore, to abandon an analysis of variance approach.

Because of the diverse nature of the data to be collected during the experiment, and because of the large number of dependent variables, it was felt that the data reduction capacities of such multi-variate techniques as factor analysis and discriminant analysis would be highly appropriate analytical tools. Having "cast the net wide" at the outset of the experiment, in order to tap as many sources of information about drivers' responses to power steering characteristics as possible, factor analysis would provide the means by which combinations of the most important variables could be selected and used as a basis on which to attempt to discriminate between groups of drivers assigned to the experimental power steering characteristics.

A three stage approach was decided upon, therefore, to provide a comprehensive and systematic evaluation of the multi-characteristic power steering system. These stages may be summarized as follows:

STAGE 1. A pilot study would be conducted in order to identify those variables which are present in drivers' verbal responses to power assisted steering. The results of the pilot study would be used to construct an evaluation questionnaire which, in combination with the performance measures described above, would provide a large amount of data on subjects' verbal and behavioural responses to the experimental power steering characteristics.

STAGE 2. Factor analysis would be used as a data reduction technique in order to generate combinations of the most important variables from Stage 1 in the form of a relatively small number of 'factors'.

STAGE 3. Discriminant analysis would be used in the final stage of the experiment in order to discriminate between groups of subjects assigned to the various experimental characteristics on the basis of the factors obtained at Stage 2.

2 PILOT STUDY

As mentioned previously, it was intended that drivers' verbal responses would provide a major source of data in the evaluation of the Cam Gears experimental multi-characteristic power assisted steering system. Consequently, it was decided to expend considerable effort in developing an appropriate subjective assessment questionnaire for use in the main part of the study. A pilot study was undertaken, therefore, to provide information about the concepts used by drivers to describe power assisted steering.

2.1 SUBJECTS

Subjects in the pilot study were all unpaid volunteers, and were drawn from various departments within the Institute including the School of Automotive Studies. Represented were members of the academic, research, secretarial and technical staff, workshop and general staff and students. A wide variability in terms of background, age and driving experience was, therefore, present in the subject population. A total of 25 subjects, 16 male and 9 female took part.

2.2 THE TEST VEHICLE

The vehicle used in the pilot study, which was later used in the main study, was a 1977 Ford Granada Ghia. The Granada is, by European standards, a large saloon car, the Ghia version having a 3 litre engine, automatic transmission and power assisted steering as standard equipment.

The only modification made to the test-vehicle for the purposes of the pilot study was the fitting of the Cam Gears multi-characteristic steering system in place of the standard item. Four switches fitted to a panel inside the front passenger's glove compartment enabled the experimenter to select the desired power steering characteristic without leaving his seat beside the driver.

2.3 METHOD

Prior to each pilot run, the experimenter selected the appropriate power steering characteristic by manipulation of the control switches inside the test-vehicle. Subjects were told that the purpose of the pilot study was to find out how drivers reacted to the experimental power assisted steering, and that they would be asked to keep up a running commentary on their reactions as they drove the car over a prescribed route.

Each subject was required to drive the experimental car, accompanied by the experimenter, over a 48 kilometre route which included rural 'B' class roads, 'A' class trunk roads, an 8 kilometre section of motorway driving and two short sections of urban driving. The route took approximately one hour to drive.

Subjects were encouraged by the experimenter to maintain a running commentary on their reactions to driving the experimental car in general, and to describe their reactions to the power assisted steering in particular, as they drove over the route. Comments from the first eight subjects, five men and three women, were simply written down by the experimenter in longhand. This method of recording was not found to be entirely satisfactory, however, and subsequently drivers' comments were tape-recorded and transcribed after the drive. Besides being a more efficient technique, tape-recordings also left the experimenter more time to follow the subject's commentary and to respond with questions when the subject's meaning was unclear. In the event that a subject 'dried up', or found it difficult to make comments spontaneously, he was asked to imagine he was describing the car's steering characteristics to someone who had never driven the car, or to try to explain how he thought that the power steering was operating. The latter technique proved very effective, in that drivers tended to adopt a 'hypothesis testing' attitude, trying to explain how the power steering operated in the light of its behaviour under different driving conditions.

Each of the four experimental characteristics and the standard power assisted steering were used in the pilot study, subjects being allocated to one of these five steering modes on a sequential basis in the order that they were recruited to take part.

2.4 RESULTS

Drivers' comments, in the form of transcribed tapes or hand-written sheets, were physically cut up into individual statements and sorted into categories by the experimenter. That is, each statement was inspected and categorized according to what the experimenter considered were its keywords or major theme. Thus, comments on the 'lightness' of the steering were placed in one category, comments on the 'sensitivity' of the steering were placed in another category and so on.

Initially, relatively few categories were identified, each containing a large number of statements. Repeated sorts were made of these large categories until it was felt that each category represented a separate, indivisable, dimension which was being used by subjects to describe some aspect of their reaction to the experimental vehicle and its steering system. Comments on other characteristics of the experimental car, for example, its general layout, were placed in a separate category, as were miscellaneous comments made by subjects which did not relate to the experimental car in any way.

On completion of the sorting procedure, eighteen categories were identified into which drivers' verbal responses to the experimental car and its power steering system could be placed. A description of these, and the two categories containing general comments on the car and miscellaneous comments, are given below. (The numbers associated with each category were assigned on a purely arbitary basis, and they should not be taken as an index of the relative importance of the category to which they refer.)

Category 1. POWER OF THE EXPERIMENTAL CAR

Comments placed in category one were primarily concerned with the engine power of the experimental car. This was generally greater than subjects were accustomed to and, although not related to the steering, comments in this category clearly indicate that the power of the car featured largely in their perceptions of the experimental vehicle. Examples of comments in this category were the following:

> "I wouldn't have passed that car if I'd been driving my own car - this has more acceleration."

> "I think I'd be more adventurous in this car - the acceleration is so much greater, I'd take advantage of it."

> "You tend to drive more smoothly in a car with a powerful engine."

The total of nineteen comments placed in this category were made by seven subjects.

Category 2. STEERING TECHNIQUE, GRIP AND HAND POSITION

Comments placed in category two were often made in response to observations from the experimenter and were mainly concerned with the way subjects held and turned the steering wheel. Examples of comments in this category were:

> "The wheel isn't slippery, you can grip with it. I'm holding the wheel loosely."

"With the Citroen (the subject's own car) you need to grip the wheel more, and put more effort into it, but with this it's very easy - you only need to hold the wheel very lightly."

"I've abandoned any attempt to drive hand-over-hand."

(This in response to the experimenter's observation that the subject had changed from a 'hand-over-hand' technique to 'feeding' the wheel through his hands.)

The total of twenty comments in this category were made by nine subjects.

Category 3. EFFECTS OF POWER ASSISTANCE ON THE GEOMETRY OF STEERING MANOEUVRES

Comments placed in category three referred to the effects that the power assisted steering was having on drivers' steering manoeuvres. Often, these effects were found by drivers to be temporary, in that, by the end of the pilot run they were no longer noticeable. Examples of comments in this category were the following:

"I don't feel too happy on shallow curvature, it's not going smoothly round the curve, it goes out and then back."

"I just wound on about three times as much steering as I needed and took a much tighter turn. There's a tendency to come to a junction, stop, and turn through ninety degrees at first."

"It (the power assistance) makes turning through large angles much easier."

The total of fourteen comments placed in this category were made by six subjects.

Category 4. GETTING USED TO THE EXPERIMENTAL CAR

Comments placed in category four refer to the need for drivers to adapt to the control characteristics of the car, that is its automatic transmission, brakes and steering, and to the size of the car. The majority of comments in this category were elicited by questions from the experimenter. Examples were the following:

> "Yes, it's fairly easy to adapt to this car because its automatic. In a manual gearbox car, all clutches are different."

> "I was surprised how quickly I adapted to the width of the car, it never presented a problem."

> "I'm just getting used to not using the accelerator too viciously. With a manual gear car, you have to increase the revs a bit first."

The total of forty-seven comments placed in this category were made by ten subjects.

Category 5. RETURN OF THE STEERING TO THE 'STRAIGHT AHEAD' POSITION

Comments placed in category five refer to the way in which the car's steering wheel returned to the straight ahead position after drivers had completed a turning manoeuvre. Examples of comments in this category were the following:

> "At the junction, I had to turn the wheel back through my hands, it didn't spin back."

> "It doesn't straighten up as rapidly as you might expect it to, it comes back gently."

> "Again, I had to pull the wheel over, it didn't return through my hands."

The total of seven comments placed in this category were made by three subjects.

Category 6. THE TEST-VEHICLE'S STEERING RATIO

Comments placed in category six were elicited by direct questions from the experimenter about the test-vehicle's steering ratio. Subjects' responses indicate either that the steering ratio of the experimental car was not noticeably different from that of their own car, or that this was not a very salient feature of the steering as far as most subjects were concerned. Examples of the comments in this category were the following:

> "I don't know if the ratio is any different (from the subject's own car)."
>
> "It feels like a low ratio."
>
> "You seem to have to turn the wheel very little, it feels like it has a small turning circle."

The total of seven comments placed in this category were made by six subjects.

Category 7. STABILITY OF THE EXPERIMENTAL CAR

Comments placed in category seven referred to the feeling of stability given by the experimental car, and many comments indicate that this gave drivers confidence in the steering. The large number of comments made suggest that this was an important characteristic for many subjects. Examples were the following:

> "I'm allowing for bumps (in the road) but there's no need - I could go fast round bends."
>
> "I noticed that in a crosswind gust I didn't have to hang on to the wheel or correct the steering."

> "It's certainly a very stable car, there's no tendency to wander on the road at all."

The total of thirty-six comments placed in this category were made by ten subjects.

Category 8. EFFORT REQUIRED TO DRIVE THE EXPERIMENTAL CAR

Comments placed in category eight refer to subjects finding the car effortless to drive. Again, the large number of comments in this category suggest that this was an important characteristic of the car for many drivers. The reason for this feeling of effortlessness appears to have been a combination of the automatic gearbox, the power assisted steering and the power of the engine. Examples of comments in this category were the following:

> "Taking the gear change away allows you to concentrate. The car reacts quickly and you are in complete control of the car with ease."

> "It's effortless. All you have to do is use the accelerator, the brake, and steer it."

> "It must be easy to drive long distances in this car."

The total of thirty four comments placed in this category were made by nine drivers.

Category 9. IMPLICATIONS OF HAVING "LESS TO DO" WHEN DRIVING THE EXPERIMENTAL CAR

Comments placed in category nine refer to the consequences of the car's being effortless to drive. Most of these comments were made in response to questions from the experimenter concerning the safety implications of a car which demands little effort to drive. Examples of comments in this category were the following:

"A lot of people think they'll fall asleep if they haven't got much to do, but it gives one more time to concentrate on the road."

"It's a good thing. You're not concerned with the mechanics, (of driving the car) you can concentrate on driving and get through difficulties better."

"Being effortless to drive increases your awareness of what's going on outside."

The total of fifteen comments placed in this category were made by eight subjects.

Category 10. SINGLE WORD DESCRIPTIONS OF THE STEERING

During the course of each pilot run drivers were asked to describe the test-vehicle's steering in a single word, or in a series of single words. Those single word descriptions which did not fit into other categories were placed in category ten. Examples of these were as follows:

"Positive", "Smooth, gentle", "Swingy".

The total of twenty four comments in this category were made by ten drivers. (Some subjects were unable to think of single words to describe the steering.)

Category 11. PREDICTED PSYCHOLOGICAL EFFECTS OF DRIVING THE EXPERIMENTAL CAR ON A REGULAR BASIS

Comments placed in category eleven were made in direct response to the experimenter's asking subjects if they thought that driving the car on a regular basis might change their driving behaviour. Would they drive any more or less aggressively, for instance, faster or more slowly, and would it change their attitudes to other road-users? Examples of the comments in category eleven were the following:

"Yes, I don't know why, but I'm driving it smoothly. It's automatic and, to me, autos make you drive less aggressively."

.... "I feel quite relaxed poodling along at 30 m.p.h. (48 k/h) behind this stream of traffic. I'd be trying to overtake in my car."

"Yes, I think you might be more prepared to give way to pedestrians and other cars because it costs you nothing to stop and go again."

The total of nineteen comments in this category were made by eight drivers.

Category 12. DRIVING SPEED IN THE EXPERIMENTAL CAR

Comments placed in category twelve were, in some cases, made spontaneously, and, in other cases, were made in response to the experimenter's questions about the speed at which subjects would normally drive. Many of the comments in this category indicated that drivers tended to underestimate their speed in the experimental car. Examples were the following:

"I'm going about 3 to 4 m.p.h. (4 to 6 k/h) faster than I normally would."

"I'm going faster now than I normally would in my own car but you don't notice it - it feels like a safer speed."

"You tend to loose a sense of speed because it's so effortless."

The total of thirty six comments in this category were made by ten drivers.

Category 13. RESPONSE CHARACTERISTICS OF THE TEST VEHICLE'S STEERING

Comments placed in category thirteen make reference to the "responsiveness" and "positive" nature of the steering. These two terms appear to have been used synonomously to describe the speed with which the experimental car responded to a steering input. In most cases, drivers felt that this was more or less instant. Examples of comments in this category were the following:

> "....it feels more positive than normal (unassisted) steering, any movement of the wheel is taken up by the car."

> "When you turn the wheel there's definitely something happening, you can feel the response straightaway."

> "It takes the heaviness out of steering, as soon as you touch the wheel, you get an instant reaction."

The total of twenty two comments in this category were made by nine drivers.

Category 14. "PLAY" IN THE STEERING

Comments placed in category fourteen referred to the amount of "play" in the test-vehicle's steering, by which subjects appeared to mean an area around the straight ahead position in which the car did not respond to the steering. Some subjects, however, commented that there was no "play" in the steering. Examples of the comments in this category were the following:

> "You need plenty of room with this (car), I wouldn't like to be forced into the side of the road - there's too much play in the steering."

"It's only the feeling that there's play in the wheel at high speeds, it doesn't actually wander."

"It doesn't seem to have much play in it."

The total of twenty nine comments in this category were made by eight drivers.

Category 15. LACK OF STEERING 'FEEL'

Comments placed in category fifteen appeared to correspond to what is commonly termed steering 'feel', that is, the force feedback characteristics of the steering. Subjects' comments tend to confirm that drivers were aware of the lack of 'feel' often associated with power assisted steering. Examples of comments in this category were the following:

"On a manual steered car, when you go round you feel the car digging in as you go round. I didn't feel that at all in this car."

"Difficult to say whether you'd be able to feel icy or greasy roads through the steering. You can feel the steering go lighter on my car on ice."

"I'm not used to the car yet, but on my car I can feel the front wheels on the road. In this car, I can't translate the movement of the steering wheel into what the front wheels are doing."

The total of twenty two comments in this category were made by eight drivers.

Category 16. ASSISTANCE CHARACTERISTICS OF THE STEERING

Comments placed in category sixteen made reference to changes in the amount of effort required to steer the car under different driving conditions. For many drivers, this appears to have been an important feature of the test vehicle's steering, reflected by the fact that this category contains more comments than any other single category. The following are some examples:

"On bends .... it seemed that the further you turned the wheel the less resistance there was, or the more assistance there was."

".... when I get there, (subject indicates the position of the steering wheel) about 40° round, there's a sudden drop in resistance."

"It feels lighter when you're going slowly. Not sure if it's the mechanics, or what one's used to, in that you expect the steering to get heavy at low speeds."

The total of forty three comments in this category were made by eight drivers.

Category 17. TENDENCY TO "OVERSTEER"

Comments placed in category seventeen made reference to subjects' tendency to "oversteer" when manoeuvreing the test-vehicle. The term "oversteer"* appears to have been used by drivers to mean that they inadvertently turned the steering wheel further than was necessary under some circumstances. Often such comments were accompanied by an explanation in terms of the subject's having expected resistance to turning the steering wheel which was absent in the experimental car. "Oversteering" tended to be a transitory phenomenon, however, having disappeared in most cases by the end of the pilot run. Examples of comments in this category were the following:

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*The use of the term "oversteer" by drivers in this context should not be confused with its formal use in the field of vehicle dynamics, where it defines a particular response characteristic of the vehicle itself.

"At low speeds you can easily oversteer because it's so positive."

"Yes I did (oversteer) a bit, I was expecting more resistance from the wheel. I'm not having that trouble now."

"It feels like in an emergency it might be possible to overcorrect your position and to oversteer."

The total of twenty five comments in this categoty were made by eight drivers.

Category 18. LIGHTNESS OF THE STEERING

Comments placed in category eighteen referred to the lightness of the test-vehicle's steering, and the tenor of these comments was generally favourable. The following were some examples:

"It's dead easy as far as the steering goes, it's very, very light."

"When you're going round corners, there's no effort at all, it's very light."

"Nice and easy to turn."

The total of thirty four comments in this category were made by ten drivers.

CATEGORY 19. COMMENTS ON OTHER FEATURES OF THE EXPERIMENTAL CAR

Comments placed in category nineteen made reference to features of the test-vehicle which were not felt to be directly relevant to its general handling qualities or to the steering. Examples of comments in this category were the following:

"The shape of the vehicle is good - you get an idea of where the front is."

"The steering wheel is nice, you get a good view of the instruments."

"The ashtray's badly placed, your hand tends to hit the gear change."

The total of thirteen comments in this category were made by six drivers.

Category 20. GENERAL COMMENTS ON MISCELLANEOUS DRIVING MATTERS

Category twenty contains general observations made by drivers concerning the task itself and unrelated driving matters. Examples of comments in this category were the following:

"I always feel more tense on the motorway, it only takes one person to make a mistake...."

"I don't think mini-roundabouts are a good idea, people still observe the original priority."

"Driving on British roads is very different from Canada - there you only need to drive in a straight line."

The total of seven comments in this category were made by five drivers.

2.5 DISCUSSION

The results of the pilot study were seen to be particularly encouraging in two respects. Firstly, they confirm that drivers do experience some difficulty in adapting to the force feedback characteristics of power assisted steering, and that drivers are aware of a lack of 'feel' as suggested in the Introduction. Secondly, the results indicate that ordinary drivers have a range of concepts at their disposal with which to describe the salient features of power assisted steering.

Of the twenty categories used to classify drivers' comments, ten were found to relate directly to the characteristics of the experimental steering system, namely, categories 3, 5, 6, 7, 13, 14, 15, 16, 17 and 18. Some indication of the relative importance of a particular category is given by the number of comments contained within it, and the number of drivers making those comments. (It should be remembered that drivers were assigned to different steering modes which are likely to have given rise to different categories of comments. It is not surprising, therefore, that no single category contained comments from all drivers.) Since the number of drivers making comments in a particular category is probably a better index of its importance than the absolute number of comments, it is possible to rank the 'steering' categories in order of importance as follows:

Category		Number of Comments	Number of Drivers
7	(Stability of the car)	36	10
18	(Lightness of the steering)	34	10
13	(Response characteristics)	22	9
16	(Assistance characteristics)	43	8
14	("Play" in the steering)	29	8
17	(Tendency to "oversteer")	25	8
15	(Lack of steering 'feel')	22	8
3	(Geometry of steering manoeuvres)	15	6
6	(Steering ratio)	7	6
5	(Return to straight ahead position)	7	3

It would seem, for example, that the stability of the experimental car (category 7) was an important feature for many drivers. This confidence in the car's steering expressed by subjects who noted that the steering was not affected by irregularities in the road, may be attributed to the hydraulic damping of disturbance inputs by the power assisted steering. When the front wheel of a manually steered car meets an irregularity in the road surface, (a pot-hole, for example) the wheel tends to be deflected. The effect on the driver depends upon the severity of this disturbance input, and may vary between a slight 'kick back' of the steering wheel in the driver's hands and the wheel being jerked from his grasp. In the case of the power steered vehicle, a disturbance input to the steering must displace the hydraulic fluid in the system before being transmitted to the steering wheel. The damping effect provided by power assisted steering can be quite high so that minor disturbance inputs go unnoticed and major inputs, which might otherwise cause the driver to temporarily lose control of the steering, are attenuated to more manageable levels. It seems likely, therefore, that it was the damping effect of the power assisted steering which gave rise to drivers' comments on the car's "stability" in category 7.

The 'lightness' of power assisted steering (category 18) also drew many comments from drivers, most of which were favourable in the sense that it made steering the car "easy" and"effortless". Similarly, the speed with which the car responded to steering inputs (category 13), was also commented on favourably by many drivers.

A feature of the experimental power steering system of which some drivers were aware was the change in the level of assistance provided by the system under different driving conditions (category 16). This may be attributed to the nature of the handwheel torque/system pressure curve shown in Figure 2 and described in the Introduction. Very often, drivers noted that the effort required to steer the experimental car was at its lowest level under conditions in which they would expect steering efforts to be highest, when driving at low speeds for example, which corresponds to the almost vertical part of the assistance curve shown in Figure 2. It is highly likely that the tendency to "over-steer" noted by many drivers (category 17) followed as a direct consequence of this difference between expected steering efforts and those actually required.

Whereas some drivers commented that there was a large amount of "play" in the test-vehicle's steering, others noted a lack of "play" (category 14). By "play", subjects appeared to be referring to an area round the straight ahead position of the steering wheel in which they detected no response to movement. The fact that some drivers found a significant amount of "play" while others found none, suggests either that drivers differ in their sensitivity to "play", or that the perception of "play" was hightened by some of the experimental characteristics and minimized by others. It remains to be seen from the results of the main experiment which of these explanations appears to be the most satisfactory.

The lack of steering 'feel', which it was argued in the Introduction is associated with power assisted steering was the subject of comment from some subjects (category 15). The majority of comments in this category were rather negative, in the sense that the force feedback characteristics of power assisted steering were compared unfavourably with those of manual steering. Again, the question of whether the design of the experimental power steering characteristics provides additional steering 'feel' as intended, remains to be answered by the results of the main study.

References to the effects of power assisted steering on the geometry of drivers' manoeuvres (category 3) indicate subjects' awareness of a certain discontinuity in their performance of steering manoeuvres. It seems likely that drivers' difficulties in this respect are related to the tendency to "oversteer" mentioned previously, with drivers having to make corrective steering adjustments during manoeuvres as a consequence of "oversteering".

Whilst drivers were invited to comment on the test vehicle's steering ratio (category 6) the majority were unable to say whether the ratio was high or low, or whether it was the same as that of their own cars. It would seem, therefore, that the steering ratio was not a particularly salient feature of the experimental car for most drivers.

The slow return of the steering to the straight ahead position noted by some drivers (category 5) is also attributable to the damping effects of power steering referred to previously. If the self-aligning torques generated at the front wheels of a car are thought of as a disturbance input which tends to 'deflect' the wheels towards the straight ahead position, the same hydraulic damping associated with power steering which attenuates the effects of other disturbance inputs will also prevent the steering wheel from returning forcefully to the straight ahead position due to the damping of self-aligning torques. The tendency for the steering wheel of a manually steered vehicle to 'spin back' through the driver's hands after making a turn is much less noticeable in a power steered vehicle, therefore, and it is this characteristic to which drivers' comments appear to have been directed.

In discussing the results of the pilot study, only those categories which relate directly to the steering characteristics of the experimental car have so far been mentioned. Of the remaining twelve categories of drivers' comments, two, categories nineteen and twenty, contain general references to the layout of the car and to the driving task which are of little relevance to the purposes of the study. Categories nineteen and twenty were not considered to be of use, therefore, in the construction of an assessment questionnaire.

Those categories which contain comments on other, non-steering aspects of the car, for example driving speed (category 12), were felt to be of importance, however, since these might be expected to vary with the type of experimental steering characteristic in use. It was, therefore, decided to use categories 1, 2, 4, 8, 9, 10, 11 and 12 in the generation of items for the assessment questionnaire. A full description of the development of the assessment questionnaire is given in a later section.

2.6 CONCLUSIONS

The purpose of the pilot study was to identify those concepts which ordinary drivers would use to describe their reactions to power assisted steering, so that a meaningful assessment questionnaire could be developed for use in the evaluation of the Cam Gears experimental power assisted steering system.

The results of the pilot study confirm that drivers experience difficulty in adapting to the force feedback characteristics of power assisted steering, and that they are aware of a lack of steering 'feel' in comparison with manual steering systems. The results also indicate that ordinary drivers have a range of concepts at their disposal with which to describe the salient features of power assisted steering.

It was found that drivers' comments could be sorted into one of twenty different categories, ten of which were directly related to steering characteristics, eight of which reflected various other aspects of drivers' reactions to the experimental car, and two of which were unrelated either to the steering or to other relevant features of the experimental car. It was decided to use the steering and non-steering categories, that is, categories 1 to 18 inclusive in the generation of items for the assessment questionnaire.

3 DEVELOPMENT OF THE ASSESSMENT QUESTIONNAIRE

3.1 BASIC REQUIREMENTS

It may be recalled from an earlier section, in which a number of methodological issues relevant to the main study were considered, that subjects were to evaluate the experimental steering characteristics in two stages. The first of these involved driving over the experimental route on a 'familiarization' run using the standard power assisted steering, and the second involved driving over the same route using one or other of the experimental steering characteristics. Thus, in the first half of the experiment, subjects were to evaluate the standard power assisted steering whilst in the second half of the experiment, subjects were to evaluate the experimental steering characteristics.

The implications of this testing procedure for the design of the assessment questionnaire were twofold. Firstly, it seemed reasonable to suppose that when subjects were asked to evaluate the standard power steering in the first half of the study, they would tend to compare the experimental car's steering with that of their own car. Similarly, when asked to evaluate one or other of the experimental characteristics in the second half of the experiment, it seemed likely that subjects would compare the experimental characteristic with the standard power assisted steering they had previously used. Indeed, it was the intention of the experimenter that subjects should be encouraged to make such comparisons so that the baseline against which evaluations were made would be known. Consequently, a basic requirement of the items contained in the assessment questionnaire was that they should be phrased in such a way as to make clear to the subject that he was being asked to make a comparison <u>between</u> steering systems rather than evaluating the test vehicle's steering on an absolute basis.

Secondly, since subjects were effectively making a separate evaluation of both the standard power assisted steering and the experimental systems, two versions of the assessment questionnaire would be required. Furthermore, in order to acquaint subjects with the content of the assessment questionnaire prior to the 'familiarization' run, it was decided that a third, practice, version of the questionnaire was also required.

Questionnaire items would need to be constructed in such a way, therefore, that only minor changes to their format would be necessary to provide a 'practice' version, a version for the assessment of the standard power steering system and a version suitable for the evaluation of the experimental steering characteristics.

In accordance with these basic requirements, three forms of an assessment questionnaire were developed for use in the main study. In form 'A', the practice version of the questionnaire, subjects were asked to compare their present car with a previous car in terms of the items presented. In form 'B', to be administered after the 'familiarization' part of the experiment, subjects were asked to compare the standard power assisted steering with that of their own car. In form 'C' of the questionnaire, to be administered after the second road-run, subjects were asked to compare the experimental steering characteristic with the standard power steering on the same items included in forms 'A' and 'B'. The way in which the items used in the questionnaire were generated is described in the following paragraphs.

3.2 GENERATING ITEMS FROM THE PILOT STUDY CATEGORIES

As noted previously, categories 1 to 18 inclusive of the pilot study comments were to be used to generate items for the assessment questionnaire.

The experimenter began by taking each of the 18 categories in turn and writing a description of its contents in which the keywords and central concepts were emphasized. These were then used as a basis on which to construct a question, or a number of questions relating to that category. For example, category 7 contained a number of comments concerning the stability of the test-vehicle. Comments indicated that the test-vehicle was relatively immune to the effects of disturbance inputs, and that this gave drivers confidence in the steering. Consequently, two items were devised for the questionnaire on the basis of category 7 comments, the first asked drivers how easy they found it to keep the car 'on course' over uneven road surfaces, the second asked drivers to rate their confidence in the steering. In accordance with the decision to phrase each item in the form of a comparison, these items appeared in the final questionnaire as shown in Appendix B (items 22 and 19 respectively).

In some cases, further items were generated when it was felt that the known design features of the experimental power steering system were especially relevant to a particular category. For example, comments in category 18 made reference to the "lightness" of the test-vehicle's steering. Since it was known that one of the experimental characteristics was designed to become 'heavier' at speed (the Speed Proportional Feel characteristic), it was decided to generate a number of items to cover the "lightness" dimension. Thus, subjects were asked how light was the vehicle's steering at low and at moderate to high speeds, (items 21 and 31 respectively). Bearing in mind that another of the experimental characteristics, the Conventional Reaction characteristic, was designed to approximate manual steering efforts, it was thought possible that such a system might be considered too heavy by drivers. Consequently, further items asked subjects whether the vehicle's steering was too heavy or too light under different driving conditions(items 18 and 32).

In generating questionnaire items from the eighteen categories of pilot study comments, therefore, an attempt was made to represent the nuances of meaning contained in those comments, and in addition, to ensure that individual items reflected the known design features of the experimental power assisted steering system to be evaluated.

3.3 GENERATION OF ADDITIONAL QUESTIONNAIRE ITEMS

Of the seventy one* items subsequently included in the assessment questionnaire, sixty were generated on the basis of the pilot study categories as described above. The remaining eleven items were included by the experimenter to reflect his own interest in the possible effects of the experimental power steering characteristics on other aspects of drivers' behaviour.

The additional items were mainly concerned with the driver's willingness to manoeuvre the experimental car under a variety of traffic conditions. For example, two of the items, 43 and 50, refer to the driver's willingness to enter smaller gaps in the traffic when driving the experimental car. Similarly, items 24and25 areconcerned with the time taken by drivers to negotiate mini-roundabouts. By providing subjects with specific examples of common manoeuvres in these additional items, it was hoped to elicit further information on the behavioural consequences of the experimental steering characteristics.

Since so little work has been done on drivers' reactions to vehicle steering characteristics, and there is, therefore, little information to indicate the sort of questionnaire item which might prove useful in a study of this type, the experimenter felt justified in adding items which had not been generated by the pilot study but which he considered to be of relevance.

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*In the three forms of the questionnaire shown in Appendix B, the items are numbered from 1 to 69. Item 57, however, comprises three parts, hence the total of 71 items.

3.4 QUESTIONNAIRE LAYOUT

The order in which items were presented in the assessment questionnaire was 'scrambled' so that similar items did not appear in close proximity. This was done in order to minimize the possible effects of previous responses on subsequent ones.

In general, a five point rating scale was given under each item, with each of the points labelled by an appropriate adjective. Thus, an item which asked drivers how quickly the test-vehicle responded to the steering in comparison with their own car (item 2, form 'B') offered the following categories of response: "much more quickly", "more quickly", "no more quickly", "more slowly" and "much more slowly". Items 7 and 57 of the questionnaire, which were concerned with uni-polar rather than bi-polar dimensions, were given a three point rating scale since it was felt that this would provide sufficient information on subjects' responses to these items.

All verbal descriptions associated with the rating scales which implied increased quantities of a dimension ("more", "greater") were placed to the left of the rating scale, and those items implying decreased quantities of a dimension ("less", "fewer") were placed to the right. This procedure is recommended by Guildford (1954) in order to help the respondant by standardizing the format of items. At the same time, however, in order to counteract the effects of response bias, care was taken to ensure that those items asking for value judgements, for example, ratings from "difficult" to "easy", were not always arranged with the 'good' dimension at one side and the 'bad' dimension at the other.

Finally, copies of form 'A' of the questionnaire were given to five members of the School's workshop staff who completed the questionnaires in the presence of the experimenter. The purpose of this exercise was to ensure that all questionnaire items were comprehensible, and that no other difficulties were experienced by respondants. A number of minor alterations to the wording of some items was found to be necessary as a result of this procedure, and these were incorporated in the final versions of all three questionnaires.

4 THE EVALUATION STUDY

It will be recalled from the Introduction, that the primary purpose of the present work was to evaluate the Cam Gears experimental multi-characteristic power assisted steering system in order to specify the 'optimal' characteristic for use in future production systems. The only constraint placed upon this evaluation by the project's sponsors was that it should involve a relatively large sample of ordinary drivers of both sexes.

The evaluation study was designed and implemented with the latter requirement in mind, therefore, and in accordance with the methodological considerations outlined in section 1.8.

4.1 SUBJECTS

Subjects for the evaluation study were 50 male and 50 female volunteers who were each paid £3.00 to take part. Subjects were licenced drivers drawn from Institute departments (other than the School of Automotive Studies), from the general population in the vicinity of the Institute, and from the student population of a local teachers' training college. No subject who had taken part in the pilot study was allowed to participate in the evaluation study.

The median age of male subjects was 29.4 years, with a range of 19 to 60 years. The median age of female subjects was 29.3 years, with a range of 19 to 58 years. Male subjects had been driving for a median of 11.4 years (range 1.5 to 40 years), and estimated that they drove a median of 18,300 Km annually (range 6,000 to 90,000 Km). Female subjects had been driving for a median of 11.2 years (range 1 to 40 years), and estimated that they drove a median of 18,000 Km annually (range 2,000 to 64,000 Km). Subjects' estimates of their prior experience with power assisted steering indicated that approximately half of the male and female groups had previously driven cars with power steering.

Further details of subjects' age, driving experience, and their familiarity with automatic transmission and power assisted steering are contained in Appendix C.

4.2 EXPERIMENTAL EQUIPMENT

4.2.1 TEST VEHICLE

The vehicle used for the evaluation study was the same as that used in the pilot study, a 1977 Ford Granada Ghia. For the purposes of the present study, however, the vehicle was modified in a number of ways as indicated in the following paragraphs.

4.2.2 MULTI-CHARACTERISTIC POWER ASSISTED STEERING SYSTEM

A detailed description of the Cam Gears experimental multi-characteristic power assisted steering system was given in section 1.5.3. This system, which was also used in the pilot study, differed considerably from the Granada's standard equipment in that a modified torsion bar and two auxilliary hydraulic pumps were employed to provide the following artificial 'feel' characteristics:

1. Fitted Load Spring Heavy. In this condition, hydraulic fluid at a constant pressure of approximately 1.4 Mpa was fed to the modified torsion bar from an electrically driven pump to inhibit the normal operation of the power assisted steering throughout its range. The effect was to increase considerably the steering efforts required of the driver under all conditions.

2. Fitted Load Spring Light. As in the previous condition, hydraulic fluid at a constant pressure was fed to the modified torsion bar from the electrically driven pump, but at a reduced level of 0.7 Mpa. The effect was to increase the steering efforts in comparison to the standard power assisted steering, but to a lesser extent than in the Load Spring Heavy condition.

3. Speed Proportional Feel. In this condition, steering 'feel' was varied by progressively inhibiting the operation of the power assisted steering as vehicle speed increased. This was accomplished by directing hydraulic fluid to the modified torsion bar from a transmission-driven pump. The effect was to provide the driver with normal power assisted steering at parking speeds but with an increased resistance to turning the steering wheel at higher speeds.

4. Conventional Reaction. In this condition, steering 'feel' was varied by inhibiting the operation of the power steering in relation to the hydraulic pressure raised in the steering rack. This was achieved by directing hydraulic fluid from the steering rack to the modified torsion bar via a reducing valve. The effect was to simulate the force feedback characteristics of manual steering, with the highest steering wheel loads occuring at parking speeds.

5. Standard Power Assistance. In this condition, no artificial 'feel' was provided by the system so that the steering behaved in the same way as that of the standard Granada.

As mentioned previously, the installation of the Cam Gears multi-characteristic rack in the experimental car was completely unobtrusive, and no visual evidence of any modification to the car's steering system was apparent to the driver. Furthermore, the switches by which the experimenter selected one or other of the experimental steering characteristics were mounted inside the passenger's glove compartment and were, therefore, invisible when the compartment lid was closed. The position of these switches is shown in Figure 1 of Appendix D.

4.2.3 RECORDING EQUIPMENT AND DISPLAYS

Two electronic display units were attached to the passenger side of the test-vehicle's dashboard, one above the other, as shown in Figure 1 of Appendix D. Both units incorporated a light emitting diode (LED) display, on which three digits could be presented in each of two 'windows', a display on/off switch and a display reset switch. The units were powered from the car's 12 v electrical circuit.

The uppermost unit was connected to a multi-turn potentiometer, fitted to the steering column, which recorded the number of wheel reversals made by the driver. Each time the steering wheel was moved back and forth through .044 rad or .244 rad, the unit recorded a "1" in the left hand window ("fine steer") or the right hand window ("coarse steer") respectively. This electronic display unit replaced a mechanical one which had been used previously to record steering reversals, but which was found to make an audible 'click' each time a reversal was counted, and which had the further disadvantage that its display could not be 'switched off'. The display of the electronic reversals counter was normally turned off, so that the driver would not be distracted by it, and was switched on only when the experimenter wished to read the display.

The lower of the two displays mounted on the test-vehicle's dashboard, in addition to its two-window LED display, also incorporated an array of four white lights. These were arranged in a horizontal line below the display and were numbered 1 to 4 from left to right. Connected to the unit, and placed on the floor of the car on the passenger's side, was a footswitch which, when depressed by the experimenter, caused one of the numbered lights to be illuminated. The sequence in which the lights were illuminated when activated by the foot switch was randomized within the unit. The purpose of this second display was to provide a subsidiary task for subjects during the test-track session in which they were required to monitor the display and to call out the number of the light which was currently illuminated. Each time the subject responded correctly, the experimenter pressed the foot switch so that the next in the random sequence of lights was generated, the unit automatically adding 1 to the recorded total of correct responses. Again, this display was normally turned off until the experimenter wished to read it, after which it was reset.

To the left of these two displays was placed a HUER "Micro-split" electronic stopwatch (also shown in Figure 1 of Appendix D). The stopwatch, which was battery driven, incorporated an LED display which was activated only when the 'READ', 'STOP' or 'START' buttons was pressed. When its function switch was turned to the 'TAYLOR' mode of operation, the watch recorded elapsed time in hours, minutes, seconds and hundredths of a second. Having started the watch at the beginning of a run, the experimenter simply pressed the 'READ' button at desired intervals to obtain the elapsed time since the button was last pressed or since the run began. The watch displayed the time for six seconds and then automatically reset itself.

The stopwatch was not permanently fixed to the test-vehicle's dashboard, but could be removed easily for use on the test-track by an external observer.

4.2.4 SAFETY EQUIPMENT

Whereas during the pilot study subjects were only required to drive the test-vehicle on public roads, it was proposed that subjects in the evaluation experiment would also carry out a number of driving manoeuvres on a specially prepared test-track. It was decided, therefore, to install a roll-over cage and a dual brake pedal to the car, and to provide crash helmets for use on the test-track.

Initially, a full roll-over cage was fitted to the test-vehicle. This was made of tubular steel and consisted of vertical supports at the A and B pillars of the car with horizontal members connecting these at roof level fore and aft. Additionally, the members running fore and aft which connected the A and B pillar supports were extended rearwards along the roof line and fixed to the rear parcel shelf. The cage was supplied and fitted by Aley Bars Ltd. of Cambridge.

This full cage arrangement was found to be unsatisfactory, however, mainly because the clamps and bolts used to connect cross members with vertical supports represented a significant safety hazard in and of themselves, but also because the clamps used would act as hinges in the event of roll-over, offering little protection to the occupants. The cage was modified, therefore, by removing the front section, that is, the vertical supports and cross member at the 'A' pillar and the horizontal members joining the A and B pillars, and by replacing the remaining clamps and bolts with sockets and pins. The rear parcel shelf, which received the rearward extending members from the vertical supports at the 'B' pillar, was also reinforced by bolting sections of tube between it and the rear wheel arches directly beneath the mounting points of the roll cage rear members. The modified roll-over cage is shown in Figure 2 of Appendix D.

Effectively, these modifications to the original installation produced a rear cage only, but this was felt to be adequate in the circumstances, and preferable to the hazards introduced by the design and installation of the complete cage. In the event of roll-over it was anticipated that the structure immediately behind the driver and passenger at the 'B' post would adequately support the roof. The rearward extending members, which were bolted to the rear parcel shelf and thence to the wheel arches of the car, would locate the 'B' post structure fore and aft, and also provide some support for the roof section at the rear. Although the roll cage no longer extended into the front of the vehicle, it was felt that occupants restrained by seat belts would still be provided with a maximum amount of survival space by the structure immediately behind them, and the large bonnet of the car would itself help maintain the integrity of the front passenger compartment if the car overturned on a flat surface. An advantage of the half cage installation was that it was much less obtrusive than the full roll over cage.

Another safety feature incorporated into the experimental vehicle was the installation of a dual control brake by He-man Dual Controls of Southampton. (A dual control clutch was unnecessary because the car had automatic transmission.) Although the number of occasions on which the dual brake could be used to advantage was felt to be few, since braking is not always the most appropriate course of action in an emergency, it was felt to be a worthwhile addition especially on the test area where a simple reduction in speed, whilst not avoiding an accident, could greatly reduce its severity.

Finally, both the subject and the experimenter were required to wear crash helmets on the test-track, and the windows of the test-vehicle were kept closed to minimize the possibility that an extended arm or leg would be crushed by the car in the event of a roll-over accident. Occupants of the test-vehicle wore seat belts at all times.

4.3 METHOD

As mentioned previously, the evaluation experiment was organized in two parts, a road drive and a test-track session, each of which was completed first with the standard power steering in use and then repeated with one of the experimental steering characteristics in use or, in the control condition, with the standard power steering again. The appropriate form of the assessment questionnaire was completed by the subject prior to the first road-run, after the first road-run and after the second road-run. Each part of the experimental procedure is described in detail below.

On arrival at the School of Automotive Studies, subjects were asked to sit in the rear of the experimental car and to provide answers to the questions on a specially prepared biographical data sheet (see Appendix E). Subjects were then told what they would be expected to do. They were told that the purpose of the experiment was to evaluate the experimental power steering system fitted to the test-vehicle, and that to do this, each subject would be required to drive the car on public roads and on a test-track in two separate experimental sessions. It was explained that they would also be asked to complete a questionnaire after each road drive, and that a practice version of this questionnaire would be administered prior to the experiment for subjects to become familiar with the nature of the questionnaire items. Subjects were normally given the practice questionnaire (form 'A' Appendix B) to fill in whilst being driven to the test area by the experimenter.

Having arrived at the test area, and when the subject had completed the practice questionnaire, he was asked to transfer to the driving seat and the experimenter moved to the front passenger seat. When the subject had adjusted his seat and made himself comfortable, the experimenter explained the position and operation of the car's minor controls, that is, the direction indicators, horn, wipers, lights and so on. If the subject had not driven with automatic transmission before, its operation was explained to him.

Subjects were then asked to check the adjustment of their driving mirrors and to put on their seat belts before being allowed to drive around the test area (but not on the test-track) for two or three minutes to familiarize themselves with the car and its controls. When the subject reported feeling confident about driving on the road, he was directed to the test-area exit.

Before joining the main road, the subject was told that the purpose of the first road-run was chiefly for him to become familiar with the standard power steering characteristics. The subject was reminded that he would be expected to complete a second questionnaire on his return from the road-run similar to the practice questionnaire he had already filled in. Subjects were instructed to drive "normally", and were advised that they were responsible for their behaviour on the road just as they were when driving their own cars, that is, they enjoyed no special priveleges because they were taking part in an experiment.

As the subject pulled out onto the main road, the experimenter switched on and reset the steering reversals counter, and started the electronic stop watch.

The route covered by drivers was divided into eighteen subsections, as shown in the sketch map in Appendix F. At the end of each subsection, the experimenter recorded the number of fine and coarse steering wheel reversals and elapsed time on a previously prepared data sheet. In addition, a number of observational data were recorded on this sheet and these are described in Appendix G. The route was approximately 50 kilometres in length, and took about 50 minutes to complete. Each section of the route depicted in Appendix F is described below.

<u>Section 1</u>. The first section, from the test area to a small town 5.9 kilometres away, was over a class 'A' trunk road. Although a 96 k/h zone and fairly straight, drivers' average speeds were relatively low because of heavy vehicles negotiating a long steep hill at the end of the section.

<u>Section 2</u>. The second section consisted of 1 kilometre of

town driving in heavy traffic. The road was winding and narrow. Parked vehicles, traffic lights and road works presented further hazards. This section was subject to a 48 k/h speed limit.

Section 3. Section three covered 1.6 kilometres of suburban roads. A 48 k/h speed limit was posted, but because this was a relatively wide, straight and lightly trafficked road, drivers tended to exceed this speed limit.

Section 4. Section four was similar to section two, in that it consisted of town driving in a 48 k/h limit. It was generally less congested however, and was 1.3 kilometres in length.

Section 5. Although section five was subject to a 96 k/h limit, it consisted of class 'A' rural roads and was relatively slow because of a number of sharp bends and slow-moving heavy vehicles. This section was 1.9 kilometres long.

Section 6. Section 6 comprised 1.0 kilometre of driving through a small village subject to a 48 k/h speed limit. The road was relatively straight and wide. Although this section included both a school and light-controlled pedestrian crossing, drivers tended to exceed the posted limit.

Section 7. Section 7 was similar to the first section, being 2.7 kilometres of class 'A' trunk road, wide with several shallow curves and a 96 k/h limit. It was a fairly busy road with a large number of heavy vehicles going to and from the motorway.

Section 8. This was a 10.4 kilometre stretch of the M1 motorway, between junctions 12 and 13. This particular section was three-lane, in good repair and relatively busy.

Section 9. Section nine was similar to sections 1 and 7, that is, a 96 k/h limit class 'A' trunk road. Like Section 7, it also carried many heavy vehicles and contained several shallow curves. It was 5.4 kilometres long.

Section 10. This section carried a 48 k/h speed limit and was a relatively short, 0.8 kilometre, section of town driving. Traffic was generally fairly light and free flowing.

Section 11. This was a 64 k/h limit section in other respects very similar to Section 10, being 0.8 kilometres long. Traffic was even lighter over this section and drivers tended to exceed the speed limit.

Section 12. Like sections 1, 7 and 9, section 12 consisted of 96 k/h limit class 'A' trunk roads. This section was 5.1 kilometres in length, contained several bends and carried many heavy vehicles.

Section 13. This was a short, 0.6 kilometre section of suburban driving in a 48 k/h zone. The main feature of this section was a particularly awkward roundabout which drivers were required to negotiate.

Section 14. Section fourteen consisted of 0.6 kilometres of town driving in a 48 k/h zone. Traffic was particularly congested at one junction in the section, which also contained two pedestrian crossings.

Section 15. Section 15 was a straight, suburban section of 1.6 kilometres, again in a 48 k/h zone. The road was wider here than on the previous section, and the traffic flowed more freely with the result that the speed limit was often exceeded.

Section 16. Section 16 comprised 4.3 kilometres of town driving, under a 48 k/h limit, and usually in congested traffic conditions. Since this part of the route was fairly demanding it was placed near the end of the road drive.

Section 17. A suburban section of 1.3 kilometres in a 48 k/h zone. Traffic tended to flow freely here and the road was straight and wide. Drivers tended to exceed the posted limit.

Section 18. The final section was 3.5 kilometres of class 'A' trunk road, with a 96k/h limit and was fairly busy. Although wide and well surfaced, shallow curves and a hill made overtaking hazardous.

The test area served as the starting point and finishing point for the road run. When subjects returned from the first road drive, they parked the car adjacent to the observer's caravan on the test-area and were given form 'B' of the assessment questionnaire. (Form 'B' required subjects to compare the standard power assisted steering to the steering of subjects' own cars.) Subjects were given tea or coffee whilst they completed the assessment questionnaire.

A plan view of the test area and the layout of the test-track is shown in Figure 1 of Appendix H. Detailed drawings of the test-track manoeuvres are shown in Figures 2 to 5. The course itself was designed in such a way that it could be completed in both clockwise and counter-clockwise directions. Although progress through the course was virtually continuous, five separate manoeuvres were involved. These were a 'lane-keeping' task, a 'roundabout' manoeuvre, a 'lane-change' manoeuvre, a 'slalom' manoeuvre, and a 'garage parking' manoeuvre.

When subjects were ready to begin the test-track session, they were instructed to drive to the starting point 'A' shown in Figure 1 of Appendix H. They were then allowed to drive slowly round the course, in a clockwise direction while the experimenter explained what they were required to do. Subjects were told that their general instructions were to drive through the course as quickly as possible without hitting any of the traffic cones which were used to mark out the course. It was emphasised that driving accurately, that is, avoiding the cones, was more important than simply driving fast.

Having negotiated the 'slalom' manoeuvre, the 'lane-change' manoeuvre was explained. Subjects were told that as they approach the 'Y' section, they would be instructed to go either left or right, but that the instruction would not be given until the car reached a line painted across the track approximately 10 metres from the intersection of the 'Y'. Subjects were therefore told to regulate their speed to give themselves enough time to respond to the left/right instruction.

Since no other directions were necessary until the subject reached the 'garage parking' manoeuvre, the experimenter explained how the subsidiary task was to be performed while drivers completed the 'roundabout' and 'lane keeping' task. Their instructions were that they should respond to the subsidiary task only when they felt they had the time available. It was emphasised that the subsidiary task was indeed subsidiary to the primary task of driving quickly and accurately through the course. On those trials designated by the experimenter as subsidiary task trials, the subject was to monitor the light display described previously, and to call out the number of the light currently illuminated. Each time the subject responded, the experimenter pressed the foot switch and another light, or the same light, would be illuminated. It was explained that the sequence in which the lights became illuminated was entirely random, so that, in theory at least, the same light could be illuminated and extinguished each time. It was emphasised that the subject should respond to the subsidiary task at his own pace, and only when he felt he had time to do so.

As he emerged from the 'lane-keeping' section of the track, the subject was instructed to drive straight ahead into the first 'garage', to stop the car as close as possible to the cones marking the end of the garage, and to reverse the car into the second garage which was placed at right angles to the first. The subject then drove forward, making a second right angle turn to bring him to point 'B', the starting point for counter-clockwise trials. The experimenter checked to make sure the subject was wearing his seat belt and gave him an appropriately sized crash helmet. If the subject queried the need to wear a helmet, or was reluctant to do so, the experimenter explained that because the test was taking place on private ground, special insurance had been arranged and that the School of Automotive Studies, which was entirely responsible for his safety, wished to offer him the maximum amount of protection in the event of an accident. In addition to the subject and experimenter wearing seat belts and helmets during test-track trials, a second observer, equipped with a fire extinguisher, remained at the track-side in case of an accident.

At the beginning of each test-track trial, the track-side observer, who also timed each trial and recorded the number of marker cones hit, signalled to the experimenter that he was ready. The subject was then told to begin the trial when he wished, and the track-side observer began timing the subject as soon as the car entered the course. Subsequently, times for each section of the course were recorded as the car passed the appropriate markers set into the tops of the cones which delineated the course. The experimenter, who accompanied subjects in the car, recorded the number of fine and coarse steering reversals made on each section, and the total number of subsidiary task responses made by the subject.

Subjects completed eight trials in each test-track session, four in one direction and four in the other. The subsidiary task was administered on trials 2, 4, 5 and 7, so that equal numbers of clockwise and counter-clockwise trials were carried out under subsidiary task and non-subsidiary task conditions. Brief pauses were made between trials, with the car at point A or point B, while the track-side observer replaced any cones which had been disturbed. At the start of each trial the subject was reminded of his instructions, and told whether or not he was to respond to the subsidiary task.

At the end of the test-track session, the car was stopped and the experimenter and subject removed their crash helmets in preparation for the second road-run. The experimenter then made an adjustment to the switches located in the glove compartment in front of him in order to select the steering characteristic to which the subject had been allocated. In the case of subjects allocated to the control group, the switches were altered and then returned to their original positions, those appropriate to the standard power assisted steering. This was done to ensure that the experimental procedure was the same for all subjects.

Before starting the second road-run, the subject was instructed to ask himself "does the car's steering feel any different this time?". If the answer to this question was "Yes", he should then ask himself "in what ways does it feel different?". As an aid to his comparison of the steering on the first and second road runs, it was suggested that the subject should try to remember how the steering behaved as he drove over various parts of the route on the first occasion and to compare this with its behaviour on the second road drive. The subject was reminded that he would be required to complete another assessment questionnaire on his return, and that this would contain essentially the same items as the two questionnaires he had filled in previously. The second road-run was then begun, the subject following the same route, and the experimenter recording the same information as on the first road-run.

At the conclusion of the second road-run, the subject was given tea or coffee and asked to complete form 'C' of the assessment questionnaire. This required him to make a comparison of the test-vehicle's steering on the second road-run with its steering on the first road-run.

When the subject was ready, the second test-track session was commenced, and this followed the same procedure as the first except that the initial practice trial was omitted. Subjects were reminded of their instructions to drive as quickly and accurately as possible, and driving times, steering wheel reversals, number of cones hit and subsidiary task scores were recorded as before.

Having completed the second test-track session, subjects were paid and then driven home by the experimenter. Any questions that subjects asked about the experiment were fully answered and subjects were thanked for taking part. Most subjects said that they had enjoyed participating and were willing to volunteer for future experiments.

A total of 103 subjects took part in the experiment and complete data was obtained for 100 of these. The sessions involving the remaining three subjects were abandoned, in one case because the test-vehicle's rear windscreen was shattered during the test-track trials, and in two cases because of poor weather conditions. The analysis of data from the evaluation study is reported in the following sections.

4.4 RESULTS

In the Introduction, the general approach to data gathering and analysis was outlined in three stages. The first stage included a pilot study to identify relevant verbal response variables for the subjective assessment questionnaire, and the selection of a number of performance measures on an a priori basis and from previous work. The results of stage one were that large amounts of data from a variety of sources were provided for analysis in stages two and three.

In stage two, it was proposed that factor analysis be used, primarily as a data reduction technique, to generate combinations of the most important variables from stage one in the form of a relatively small number of factors. It was then proposed that discriminant analysis be employed in the third stage of the data analysis to differentiate between groups of subjects allocated to the five power steering systems on the basis of the factors derived in stage two.

The results of the factor analyses and discriminant analyses are reported in detail below, and are prefaced by a brief description of these techniques. In addition, the results of a number of analyses of variance and covariance which were carried out on the test-track data, are also reported. The purpose of these latter analyses was to examine the effects of the subsidiary task on primary task performance and to assess the efficacy of the subsidiary task as a measure of 'spare mental capacity'.

The raw data from the experiment, that is, subjects' biographical data, their responses to Questionnaires 'B' and 'C', the performance data from the two road-run and two test-track sessions, were placed onto a computer file for subsequent statistical analysis. A listing of this raw data file is available in the School of Automotive Studies Library.

4.4.1 INTRODUCTION TO FACTOR ANALYSIS

Data from Questionnaire 'B', Road-run 1, and Test-track 1 were analysed, separately and together, using the statistical package for the Social Sciences (SPSS) subprogram "Factor" (Nie et al 1975). A similar procedure was adopted for the data from Questionnaire 'C', Road-run 2 and Test-track 2. The two sets of data from the first and second parts of the experiment were analysed independently, since data from Questionnaire 'B', Road-run 1 and Test-track 1 were relevant to the evaluation of the standard power steering system, whilst data from Questionnnaire 'C', Road-run 2 and Test-track 2 were relevant to the evaluation of the experimental power steering systems.

The particular version of SPSS used in the analysis was SPSS Mark 7. The package was run on a CDC 7600 series computer at the University of Manchester Regional Computer Centre which was accessed remotely. The SPSS subprogram "Factor" provides a number of factor analytic methods, and several options are available with each method. All the analyses reported here were of the PA1 type, and Varimax rotation was employed in each case to obtain an orthogonal final solution.

Factoring method PA1 provides a principal components solution which has a number of advantages over other types of factor analysis. The model adopted by principal components analysis is a relatively simple one, in that it makes no assumptions about unique variance components of factors, but rather, derives each factor as an exact mathematical transformation of the original variables. Principal components also have the advantage of being orthogonal, or statistically unrelated, to each other. In addition, principal components analysis makes no particular assumptions about the nature of the variables used.

The first principal component is defined as that linear combination of the original variables which accounts for more of the total variance in the data than any other linear combination of the variables. The second principal component is defined as that linear combination of the original variables which accounts for more of the remaining variance than any other linear combination, and which is orthogonal to the first principal component. Subsequent principal components are defined in a similar way, each accounting for as much of the remaining variance as possible, and each statistically unrelated to the others. In general, the same number of principal components will be extracted as there are variables entering into the analysis. For a detailed discussion of principal components analysis, the reader is referred to Overall and Klett (1972), chapter 3.

The initial factor solution provided by principal components analysis does not necessarily produce factors which are theoretically meaningful or conceptually simple. The initial solution seeks only to extract factors which account for the maximum amount of variance and which are orthogonal to each other. The relationships among the variables used to produce the initial factor solution are often better expressed after one or other method of rotation has been employed. In geometric terms, all methods of rotation attempt to re-locate factor axes in a multidimensional space so that a more parsimonious explanation of the relationship between clusters of variables and the factors becomes apparant. Whilst rotation of the factor axes alters the loadings of variables on the factors, it does not affect the relationships amongst the variables nor, if an orthogonal rotation is employed, does it affect the independence of factors.

Varimax rotation seeks to provide a simpler, more meaningful final solution by simplifying the columns of the factor matrix, that is to say, by making the factor loading of each variable as close as possible to 1 or 0. In effect, Varimax rotation, as its name suggests, serves to maximize the variance of the factor loadings. It can be readily seen that, by giving each variable a very high loading (close to 1) or a very low loading (close to 0), the task of interpreting a given factor is made easier. Furthermore, Varimax rotation also provides an orthogonal final solution, so that the rotated factors are statistically unrelated to one another.

As mentioned above, it is possible to extract as many principal components as there are variables entering into the analysis. However, most of the variance in the original variables is usually accounted for by a relatively small number of principal components, and the number of principal components extracted by subprogram "Factor" can be limited by an appropriate control card. In all principal components analyses reported here, the number of factors extracted was limited to that sufficient to account for approximately 75% of the total variance.

In order to interpret the meaning of each factor, only the highest loading variables were taken into account. Although principal components are defined in terms of a linear combination of all the variables, therefore, only those variables having high loadings on a given factor were considered in its interpretation. To distinguish the factors interpreted in this way from the extracted principal components, interpreted factors were designated "NFactors".

The loadings or weights used to define each "NFactor" were taken from the rotated factor matrix output by the SPSS program, these weights being the correlation coefficients between each variable and the respective principal component. By using the correlation coefficients to define NFactors, both the extent and direction of the relationship between each variable and a given factor is made clear. In addition, an index of the relative importance of each variable in defining a given factor is also provided by squaring the correlation coefficient, which then indicates the proportion of variance accounted for by that variable.

Having interpreted the factors in terms of a subset of the highest loading variables, it was felt to be important to check the validity of these simplified NFactors. A series of Pearson Product Moment correlations was computed, therefore, between the factor scores output by the SPSS program and based on weighted combinations of all the variables, and factor scores computed from the subset of variables and weights used to define the NFactors. The correlation coefficients obtained are shown in Appendix I, and are generally very high, indicating that the simplified NFactors are a close approximation to the principal components extracted by the SPSS program.

In the course of re-defining the principal components to provide simplified NFactors, however, some loss of orthogonality occured. This is evident from the intercorrelations between the NFactors shown in Tables 1 to 6 of Appendix J, some of which are moderately high. Since the main purpose of factor analysing the data was to provide composite variables for subsequent discriminant analysis, however, and since discriminant analysis makes no assumptions concerning the independence of discriminant variables, this loss of orthogonality was not felt to be important.

Before the results of individual analyses are reported, a number of further points concerning the interpretation of NFactors should be made. As noted above, the weights used to define the NFactors were the correlation coefficients between variables and factors given in the rotated factor matrix. When considering the meaning of a factor, therefore, positively weighted variables may be thought of as having a positive relationship with the factor, and negatively weighted variables a negative relationship. Thus, if variables A and B are the two most highly weighted variables on a given factor, and A is positively weighted and B negatively weighted, the factor may be described as "A" and "not B". Alternatively, where there are negatively weighted and positively weighted variables, it is possible to follow Overall and Klett (1972) and describe the factor as contrasting individuals who are "A" and individuals who are "B".

To some extent, the interpretation will depend upon the experimenter's interest. If he is interested in individual differences between subjects, he may be wise to adopt the 'contrast' notion. Thus, Overall and Klett's analysis of psychiatric profiles contrasted those patients with one set of symptoms and those patients having another set of symptoms. If the experimenter's interest is in the nature of the factors themselves, however, and their ability to summarise the relationships between their component variables, then he may opt for the former approach, where variables are simply seen as positively or negatively correlated with a given factor.

Since the factor analyses reported here were carried out to provide composite variables for a later series of discriminant analyses, interpretations of the NFactors were made by adopting the 'correlation' approach. The interpretation of each NFactor is described below in terms of the contribution of the variables to a high positive score on that factor. Thus, if variable A is negatively weighted, then the factor is described in terms of "not A". For example, if the variable "Easy to get used to" is negatively weighted, a subject with a high positive score on the factor to which the variable relates must have responded "Difficult to get used to" on that item of the questionnaire, and "Difficult to get used to" appears in the description of that factor.

The results of the six principal components analyses conducted on the data from Questionnaires 'B' and 'C', the first and second road-runs and first and second test-track sessions are reported in the following sections. A table containing the number of factors or principal components extracted, the amount of variance accounted for by each factor in the form of its eigenvalue, the amount of variance accounted for expressed as a percentage and expressed as a cumulative percentage, is given immediately prior to each set of results.

4.4.2 FACTOR ANALYSIS A (ITEMS FROM QUESTIONNAIRE 'B')

The variables included in the first factor analysis were the individual items from Questionnaire 'B', in which subjects were asked to compare the experimental car's steering with that of their own car after the first, familiarisation, road-run (see Appendix B). The means and standard deviations of subjects' scores on each item from Questionnaire B are given in Table 1 of Appendix M, and these indicate that, in general, scores were grouped around the middle or 'neutral' category on each item. On item 1, however, (for which a three point rating scale was used) the extremely high mean and small standard deviation indicate that almost all subjects found the standard power steering "very different" from that of their own car.

Table 1, below, gives the eigenvalues and percent of variance accounted for by the twenty factors derived in Factor Analysis A.

TABLE 1. Eigenvalues, percent of variance and cumulative percent of variance accounted for by the twenty factors derived in Factor Analysis A. Data are the items from Questionnaire B in which subjects compared the experimental car's steering with that of their own car.

Factor	Eigenvalue	% of Variance Accounted for	Cum.% Variance Accounted for
1	14.47	20.4	20.4
2	3.99	5.6	26.0
3	3.80	5.3	31.4
4	3.12	4.4	35.7
5	2.89	4.1	39.8
6	2.71	3.8	43.6
7	2.30	3.2	46.9
8	2.14	3.0	49.9
9	2.10	3.0	52.9
10	1.95	2.7	55.6
11	1.76	2.5	58.1
12	1.64	2.3	60.4
13	1.45	2.0	62.4
14	1.39	2.0	64.4
15	1.31	1.9	66.2
16	1.29	1.8	68.0
17	1.23	1.7	69.8
18	1.21	1.7	71.5
19	1.15	1.6	73.1
20	1.10	1.5	74.6

Each factor from Factor Analysis A is named, its highest-loading variables and their weights listed, and an interpretation of the meaning of a high positive score on the factor is given below.

NFACTOR 1A* "Difficult to position car and to judge the amount of effort required, lack of confidence"

The highest loading variables on the first factor were:

Item 9	Difficulty in positioning the car, right angle turns	+ .77
Item 11	Difficulty in judging the amount of effort on right angle turns	+ .76
Item 5	Easy to get used to	- .71
Item 45	Having to think about the steering	+ .70
Item 36	Difficulty in judging effort on sharp bends	+ .69
Item 20	Difficulty in positioning the car entering roundabouts	+ .65
Item 19	Degree of confidence in the steering	- .64
Item 35	Difficulty positioning the car on bends	+ .63
Item 24	Time on mini-roundabouts	+ .53
Item 10	Tendency to oversteer	+ .53
Item 42	Difficulty positioning the car when changing lanes	+ .43
Item 44	Sudden changes in effort	+ .42

A high positive score on factor 1 indicates that the driver had difficulty in positioning the car, had difficulty in judging the amount of effort required to steer the car, found the steering difficult to get used to, did not feel confident in the steering and tended to oversteer. Factor 1 is concerned with the difficulties experienced in manoeuvring the car under normal urban driving conditions.

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*The postcripts A, B, C, D, E and F are used to identify the particular factor analysis from which a factor has come, and were adopted in order to remove the ambiguity which would otherwise occur in the reporting of the discriminant analyses in later sections, some of which were carried out on factors from more than one factor analysis.

NFACTOR 2A "Difficult to keep on course, difficult to control changing lanes at speed"

The highest loading variables on factor two were:

Item 54	Difficulty maintaining lane position at high speed	+ .84
Item 53	Difficulty maintaining lane position at moderate speed	+ .82
Item 52	Difficulty controlling the car changing lanes at high speed	+ .75
Item 29	Difficulty positioning the car on straight roads	+ .70
Item 51	Difficulty controlling the car changing lanes at moderate speeds	+ .65
Item 55	Having to make many corrective movements	+ .58
Item 34	Confidence in the steering at high speeds	- .52
Item 28	Easy to keep on course over uneven roads	- .49
Item 62	Control over the car	- .41
Item 42	Difficulty positioning the car when changing lanes	+ .41
Item 30	Confidence at moderate speeds	- .39

A high positive score on factor 2 indicates that drivers found it difficult to keep the car on course at speed, had difficulty controlling the car during lane-change manoeuvres, had to make many corrective steering movements and lacked confidence in the steering at moderate speeds. Factor 2 is concerned with problems experienced in 'open road' driving, especially at speed and when driving in a straight line.

NFACTOR 3A "<u>Willingness to manoeuvre the car in traffic</u>"

The highest loading variables on factor 3 were:

Item 15	Willingness to squeeze past slow moving vehicles	+ .81
Item 43	Willingness to enter small gaps in the traffic	+ .69
Item 27	Willingness to 'nip in and out' around parked vehicles	+ .58
Item 25	Taking longer at mini-roundabouts	- .55
Item 16	Holding back in face of oncoming traffic	- .53
Item 38	Driving faster through bends	+ .49
Item 17	Willingness to steer around pedestrians	+ .42
Item 20	Difficulty positioning the car entering roundabouts	- .30
Item 42	Difficulty positioning the car when changing lanes to pass parked vehicles	- .30

A high positive score on factor 3 indicates that drivers were willing to manoeuvre the car in traffic, were 'bolder' in their driving style and found it easy to position the car in traffic.

NFACTOR 4A "<u>Driving faster, overtaking more, easy to control the car changing lanes at speed</u>"

The highest loading variables on factor 4 were:

Item 37	Driving faster on straight roads	+ .82
Item 60	Driving faster overall	+ .82
Item 40	Frequency of overtaking	+ .78
Item 38	Driving faster through bends	+ .43
Item 16	Holding back in face of oncoming traffic	- .41
Item 41	Confidence when overtaking	+ .32
Item 61	Driving more smoothly	+ .32
Item 51	Difficulty changing lanes at moderate speeds	- .31
Item 52	Difficulty changing lanes at high speeds	- .29

A high positive score on factor 4 indicates that drivers felt that they drove faster and overtook more frequently in the experimental car, had more confidence when overtaking and felt better able to control the car when changing lanes at speed on the motorway.

NFACTOR 5A "Steering too light, lack of confidence"

The highest loading variables on factor 5 were:

Item 32	Steering too light at moderate to high speeds	+ .79
Item 64	Steering too light overall	+ .78
Item 34	Confidence in steering at high speeds	- .50
Item 18	Steering too light at low speeds	+ .49
Item 19	Confidence in the steering	- .41
Item 62	Control over the car	- .38
Item 55	Corrective steering movements	+ .31
Item 30	Confidence at moderate speeds	- .31
Item 41	Confidence when overtaking	- .30

A high positive score on factor 5 indicates that drivers felt that the steering was too light and that they did not feel confident in the steering.

NFACTOR 6A "Favourable reaction to the steering, having less to do"

The highest loading variables on factor 6 were:

Item 7	Lightness of the steering at parking speeds	+ .84
Item 21	(As above, item duplicated in questionnaire)	+ .79
Item 65	Lightness of the steering overall	+ .74
Item 31	Lightness of the steering at moderate speeds	+ .32
Item 59	Having less to do because of the brakes	+ .34
Item 57	Having less to do because of the steering	+ .25
Item 69	Willingness to park on opposite side of road	+ .26
Item 63	Becoming more frustrated	- .26

A high positive score on factor 6 indicates that drivers found the steering light at parking speeds and light in general, but, in contrast to factor 5, the steering was not found to be "too light". Drivers also found they had less to do, partly because of the steering, and became less frustrated, which suggests a more favourable reaction to the lightness of the steering than was found in factor 5.

NFACTOR 7A "Sensitivity, responsiveness, good 'feel'"

The highest loading variables on factor 7 were:

Item 3	Sensitivity of the steering in the straight ahead position	+ .84
Item 2	Speed of response of the steering	+ .80
Item 8	Forcefulness of return to straight ahead position	+ .50
Item 31	Lightness of the steering at moderate to high speeds	+ .41
Item 49	Difficulty in telling how much grip between front wheels and the road	- .32
Item 65	Lightness of the steering overall	+ .24
Item 6	Amount of play in the steering	- .24
Item 10	Tendency to oversteer	+ .24

A high positive score on factor 7 indicates that drivers found the steering sensitive around the straight ahead position, found the steering responsive and with good 'feel', and found that they tended to oversteer.

NFACTOR 8A "<u>Having less to do because of the transmission and brakes</u>"

The highest loading variables on factor 8 were:

Item 58	Having less to do because of the transmission	+ .79
Item 56	Having more to do	- .67
Item 59	Having less to do because of the brakes	+ .46
Item 26	Difficulty in judging amount of effort at roundabouts	- .31
Item 10	Tendency to oversteer	+ .30
Item 61	Driving more smoothly	+ .29

A high positive score on factor 8 indicates that drivers found they had less to do in driving the experimental car because of the automatic transmission and power brakes, found it easy to judge the amount of effort required to steer the car and drove more smoothly. Factor 8 is concernedwith drivers' reactions to the car's transmission and brakes coupled with two less important steering variables.

NFACTOR 9A "<u>Heavier steering and more confidence at low speeds, difficult to judge effort on sharp turns</u>"

The highest loading variables on factor 9 were:

Item 33	Effort greater when driving slowly than fast	+ .76
Item 47	Effort greater when cornering hard than when cornering gently	+ .65
Item 71	More confidence at low speeds than at high speeds	+ .34
Item 36	Difficulty in judging effort on sharp bends	+ .32
Item 39	Likelihood of crossing white line on bends	+ .29
Item 26	Difficulty in judging effort entering roundabouts	+ .28
Item 41	Confidence when overtaking	- .26

A high positive score on factor 9 indicates that drivers found the steering too heavy at low speeds, had difficulty judging the amount of effort and positioning the car when making sharp turns, and felt more confident in the steering at low than at high speeds.

NFACTOR 10A "Power of the car, less frustration, having more control"

The highest loading variables on factor 10 were:

Item 4	Power of own car by comparison with this car	- .73
Item 63	More frustrated in this car	- .46
Item 62	Having more control over the car	+ .34
Item 59	Having less to do because of the brakes	+ .31
Item 61	Able to drive more smoothly	+ .30
Item 67	Feeling more relaxed in the car	+ .28
Item 39	Likelihood of crossing white line on bends	+ .27
Item 45	Having to think about steering	+ .24

A high positive score on factor 10 indicates that drivers felt that the experimental car was more powerful than their own, that they were less frustrated in the experimental car and felt they had more control, had less to do because of the brakes, were able to drive more smoothly, felt more relaxed, were more likely to cross the white line on bends and had to think about the steering. Factor 10 is concerned with the driver's response to the power of the car rather than its steering characteristics.

NFACTOR 11A "More alert and anticipatory due to lack of 'feel'"

The highest loading variables on factor 11 were:

Item 68	More alert in the experimental car	+ .69
Item 12	Moving out earlier to pass parked vehicles	+ .65
Item 17	More likely to steer around pedestrians	+ .42
Item 49	Difficulty in telling how much grip between front wheels and the road	+ .41
Ote, 35	Difficulty positioning car on bends	- .26
Item 28	Easy to keep car on course on uneven roads	+ .23

A high positive score on factor 11 indicates that drivers felt more alert, moved out earlier to pass parked vehicles, were more likely to steer around a pedestrian crossing the road, had difficulty in telling how much grip there was between the front wheels and the road, found it easy to position the car on bends and to keep on course over uneven roads. The increased alertness associated with factor 11 appears to be related to anticipatory and cautious behaviour (items 12 and 17), and with the lack of steering 'feel' (item 49). The implication is that drivers' increased alertness was a response to the car's steering characteristics.

NFACTOR 12A "Driving more safely, more precisely, and feeling more relaxed and confident"

The highest loading variables on factor 12 were:

Item 70	Driving more safely	+ .78
Item 39	Likelihood of crossing the white line on bends	- .49
Item 67	Feeling more relaxed in the car	+ .32
Item 30	Confidence at moderate speeds	+ .28
Item 55	More corrective steering movements	- .27
Item 69	Willingness to park on other side of road	+ .26
Item 34	Confidence at high speeds	+ .25

A high positive score on factor 12 indicates that drivers felt that they were driving more safely in the experimental car, were more relaxed and confident at speed, were less likely to cross the white line on bends, needed to make fewer corrective steering movements and were more willing to park on the other side of the road. The inclusion of items 39, 69 and 55 suggest that driving 'more safely' is associated with an ability to steer accurately and precisely in subjects' minds.

NFACTOR 13A "Willingness to enter small gaps in traffic on the M1 and in town, difficult to keep on course over straight roads"

The highest loading variables on factor 13 were:

Item 50	Willingness to accept small gaps when changing lanes on the M1	+ .69
Item 69	Willingness to park on other side of road	+ .60
Item 43	Likelihood of entering small gaps in traffic	+ .39
Item 29	Willingness to 'nip in and out' around parked vehicles	+ .34
Item 28	Easy to keep on course over uneven roads	- .28
Item 12	Tendency to move out earlier when passing parked vehicles	- .27
Item 52	Difficult to change lanes at high speed on the M1	- .22

A high positive score on factor 13 indicates that drivers were willing to accept smaller gaps in traffic, found it easier to manoeuvre the car, but difficult to position the car on straight roads and to keep on course over uneven roads. Factor 13 contrasts drivers' willingness to manoeuvre the car laterally (which was also noted in factor 3), with their difficulty in controlling the car longitudinally (which was absent in factor 3).

NFACTOR 14A "Returning to own lane earlier, less play in steering"

The highest loading variables on factor 14 were:

Item 14	Returning to lane earlier after passing parked vehicle	+ .74
Item 6	Play in steering	- .50
Item 30	Confidence in steering at moderate speeds	+ .32
Item 8	Forcefulness of return to straight ahead	- .28
Item 59	Less to do because of the brakes	+ .27
Item 67	More relaxed in the car	+ .24
Item 18	Steering too light at low speeds	+ .24

A high positive score on factor 14 indicates that drivers tended to return to their lane earlier having passed a parked vehicle, felt that there was less play in the steering, were more confident at moderate speeds, found the steering too light at low speeds but were more relaxed in the experimental car than when driving their own cars.

NFACTOR 15A "Aggressive driving, cutting corners"

The highest loading variables on factor 15 were:

Item 46	Cutting corners, major to minor roads	+ .65
Item 66	Driving more aggressively	+ .63
Item 49	Difficult to tell how much grip between front wheels and the road	- .39
Item 26	Difficult to judge effort at roundabouts	+ .31
Item 27	Willingness to 'nip in and out' around parked vehicles	+ .23
Item 57	Having less to do because of the steering	+ .23

A high positive score on factor 15 indicates that drivers tended to drive more aggressively, tended to cut corners, were willing to 'nip in and out' around parked vehicles, found it easy to tell how much grip there was between the front wheels and the road, but found it difficult to judge the amount of effort required to steer the car when entering roundabouts.

NFACTOR 16A "<u>Unable to steer accurately at low speeds, more likely to steer around pedestrians</u>"

The highest loading variables on factor 16 were:

Item 22	Likely to form second queue at traffic lights	- .59
Item 44	More sudden changes in effort required	+ .43
Item 17	More likely to steer around pedestrians	+ .39
Item 61	Able to drive more smoothly	- .39
Item 18	Steering too light at low speeds	+ .28
Item 71	More confident at low speeds than high speeds	- .26
Item 49	Difficult to tell how much grip between the front wheels and the road	+ .24

A high score on factor 16 indicates that drivers were unable to steer accurately at low speeds, finding the steering too light, and felt more confident at high speeds than at low speeds. Drivers were, however, more likely to steer around a pedestrian crossing the road than to stop for him.

NFACTOR 17A "<u>Holding back, lightness of the steering</u>"

The highest loading variables on factor 17 were:

Item 23	Willingness to wait one's turn at mini-roundabouts	+ .76
Item 31	Lightness of the steering at moderate to high speeds	+ .47
Item 42	Difficulty positioning the car changing lanes	- .31
Item 16	Tendency to hold back	+ .26
Item 65	Lightness of steering overall	+ .24

A high positive score on factor 17 indicates that drivers tended to hold back in tight traffic situations and found the steering relatively light.

NFACTOR 18A "<u>Difficult to judge the straight ahead position, driving less aggressively</u>"

The highest loading variables on factor 18 were:

Item 48	Difficult to tell when the wheels are straight ahead	+ .72
Item 38	Speed through bends	+ .31
Item 66	Driving less aggressively	- .28
Item 41	Confidence when overtaking	- .26
Item 65	Difficult to judge effort entering roundabout	+ .26

A high positive score on factor 18 indicates that drivers found it difficult to tell when the wheels were straight ahead, drove faster through bends than they would in their own cars, but felt that they drove less aggressively and were less confident when overtaking.

NFACTOR 19A "<u>Passing closer to parked vehicles, play in the steering</u>"

The highest loading variables on factor 19 were:

Item 13	Passing closer alongside parked vehicles	+ .80
Item 6	Play in the steering	+ .39
Item 66	Driving aggressively	- .32
Item 71	More confidence at low than at high speeds	+ .22
Item 57	Having less to do because of the steering	+ .20

A high positive score on factor 19 indicates that drivers felt that they passed closer alongside parked vehicles, felt that there was more play in the steering, drove less aggressively and were more confident at low than high speeds.

NFACTOR 20A "Steering different from own car, having less to do"

The highest loading variables on factor 20 were:

Item 1	Difference in steering compared with own car	+ .80
Item 57	Having less to do because of the steering	+ .45
Item 8	Forcefulness of return to straight ahead	+ .27
Item 6	Play in steering	+ .21

A high positive score on factor 20 indicates that drivers found the steering different from that on their own cars and found that they had less to do when driving the experimental car.

4.4.3 FACTOR ANALYSIS B (VARIABLES FROM ROAD-RUN 1)

The variables included in Factor Analysis B were the time, number of fine steering reversals and number of coarse steering reversals recorded on each of the eighteen sections of the route, (see Appendix K). The means and standard deviations of these variables are given in Table 2 of Appendix M, where it can be seen that the 'fine steering reversals' variable was associated with relatively more variability than the 'coarse steering reversals' and 'time' variables. This is reflected in the fact that the first factor reported below which, by definition, accounts for a larger percentage of the total variance than subsequent factors, is exclusively related to the number of fine steering reversals made on each section of the route.

The eigenvalues and percent of variance accounted for by the first sixteen factors from this analysis are given in Table 2 below.

TABLE 2 Eigenvalues, percent of variance and cumulative percent of variance accounted for by the first sixteen factors derived in Factor Analysis B. Data are the variables from Road-run 1.

Factor	Eigenvalue	% of Variance Accounted for	Cum.% Variance Accounted for
1	14.24	26.4	26.4
2	3.92	7.3	33.6
3	2.82	5.2	38.9
4	2.67	4.9	43.8
5	2.28	4.2	48.0
6	2.14	4.0	53.0
7	1.88	3.5	55.5
8	1.82	3.4	58.9
9	1.79	3.3	62.2
10	1.49	2.7	64.8
11	1.41	2.6	67.5
12	1.33	2.5	69.9
13	1.21	2.2	72.2
14	1.18	2.2	74.4
15	1.12	2.1	76.4
16	1.03	1.9	78.3

Each factor from Factor Analysis B is named, its component variables and their weights listed, and an interpretation of a high positive score on that factor is given below.

NFACTOR 1B "Fine steering reversals"

The highest loading variables on factor 1 were:

Variable 2	Fine steer, test area to Ampthill	+ .86
Variable 5	Fine steer, Ampthill	+ .54
Variable 8	Fine steer, Ampthill to Flitwick	+ .76
Variable 11	Fine steer, Flitwick	+ .79
Variable 14	Fine steer, Flitwick to Westoning	+ .82
Variable 17	Fine steer, Westoning	+ .71
Variable 20	Fine steer, Westoning to the M1	+ .87
Variable 23	Fine steer, M1	+ .84
Variable 26	Fine steer, M1 to Marston	+ .90
Variable 29	Fine steer, Marston	+ .73
Variable 32	Fine steer, Marston suburban	+ .85
Variable 35	Fine steer, Marston to Kempston	+ .91
Variable 38	Fine steer, Kempston roundabout	+ .79
Variable 41	Fine steer, Kempston	+ .63
Variable 47	Fine steer, Bedford	+ .83
Variable 52	Fine steer, Bedford Ampthill Road	+ .81
Variable 53	Fine steer, Bedford to test area	+ .82

A high positive score on factor 1 indicates that drivers made many fine steering reversals on all sections of the route.

NFACTOR 2B "Coarse steer, suburban and trunk roads"

The highest loading variables on factor 2 were:

Variable 45	Coarse steer, Kempston to Bedford	+ .61
Variable 54	Coarse steer, Bedford to Test Area	+ .59
Variable 36	Coarse steer, Marston to Kempston	+ .57
Variable 21	Coarse steer, Westoning to M1	+ .57
Variable 15	Coarse steer, Flitwick to Westoning	+ .54
Variable 9	Coarse steer, Ampthill to Flitwick	+ .30

A high positive score on factor 2 indicates that drivers made many coarse steering reversals on suburban and trunk roads. An important feature of factor 2 is the absence of coarse steering reversals on urban and motorway sections of the route.

NFACTOR 3B "Coarse steer and time on M1 and Test Area to Ampthill"

The highest loading variables on factor 3 were:

Variable 24	Coarse steer, M1	+ .87
Variable 9	Coarse steer, Ampthill to Flitwick	+ .49
Variable 22	Time, M1	+ .34
Variable 3	Coarse steer, Test Area to Ampthill	+ .34
Variable 39	Coarse steer, Kempston roundabout	+ .32
Variable 1	Time, Test Area to Ampthill	+ .31

A high positive score on factor 3 indicates that drivers made many coarse steering reversals and drove more slowly on the M1, made many coarse steering reversals from Ampthill to Flitwick and in Kempston, and made many coarse steering reversals and drove more slowly from the Test Area to Ampthill.

NFACTOR 4B "Steering reversals Kempston"

The highest loading variables on factor 4 were:

Variable 42	Coarse steer, Kempston urban	+ .79
Variable 41	Fine steer, Kempston urban	+ .52
Variable 39	Coarse steer, Kempston roundabout	+ .50
Variable 51	Coarse steer, Bedford Ampthill Road	+ .36
Variable 27	Coarse steer, M1 to Marston	+ .26

A high positive score on factor 4 indicates that drivers made many steering reversals in Kempston and many coarse steering reversals in Bedford Ampthill Road and from the M1 to Marston.

The most important variables were coarse and fine steering reversals in Kempston. This section included an awkwardly shaped roundabout, a particularly difficult intersection, a pedestrian crossing and heavy traffic in a 48 k/h restricted zone.

NFACTOR 5B "Time, coarse steer, fine steer, Ampthill"

The highest loading variables on factor 5 were:

Variable 4	Time, Ampthill	+ .84
Variable 6	Coarse steer, Ampthill	+ .65
Variable 5	Fine steer, Ampthill	+ .31

A high positive score on factor 5 indicates that drivers drove slowly and made many steering reversals in Ampthill, a congested urban section of the route with narrow winding roads and a 48 k/h speed restriction.

NFACTOR 6B "Time, coarse steer, fine steer, Westoning"

The highest loading variables on factor 6 were:

Variable 16	Time, Westoning	+ .88
Variable 18	Coarse steer, Westoning	+ .79
Variable 17	Fine steer, Westoning	+ .33

A high positive score on factor 6 indicates that drivers drove slowly and made many steering reversals over a section of the route which comprised a relatively straight road through a small village with a 48 k/h speed restriction.

NFACTOR 7B "Coarse steer, time, fine steer, Flitwick"

The highest loading variables on factor 7 were:

Variable 12	Coarse steer, Flitwick	+ .87
Variable 10	Time, Flitwick	+ .70
Variable 11	Fine steer, Flitwick	+ .44

A high positive score on factor 7 indicates that drivers made many steering reversals and drove slowly through Flitwick, a winding, congested section of the route with a 48 k/h speed restriction. An interesting feature of factor 7 is that the relative importance of the 'time' and 'coarse steer' variables has been reversed in comparison to their order of importance on factors 5 and 6. That is to say, more of the variance in scores on factor 7 is accounted for by the number of coarse steering reversals made by drivers than is accounted for by their driving speed, whereas the reverse was true of these variables with respect to factors 5 and 6.

NFACTOR 8B "Time, coarse steer, fine steer, Bedford Ampthill Road"

The highest loading variables on factor 8 were:

Variable 49	Time, Bedford Ampthill Road	+ .82
Variable 51	Coarse steer, Bedford Ampthill Road	+ .71
Variable 50	Fine steer, Bedford Ampthill Road	+ .33

A high positive score on factor 8 indicates that drivers drove slowly and made many steering reversals in Bedford Ampthill Road, a suburban section of the route with a 48 k/h speed restriction.

NFACTOR 9B "Time and coarse steer Marston, fine steer Ampthill"

The highest loading variables on factor 9 were:

Variable 31	Time, Marston suburban	+ .73
Variable 33	Coarse steer, Marston suburban	+ .73
Variable 5	Fine steer, Ampthill	+ .41

A high positive score on factor 9 indicates that drivers drove slowly and made many coarse steering reversals in Marston, a section of urban driving with a 64 k/h speed restriction, and made many fine steering reversals in Ampthill, a section of congested urban driving with a 48 k/h speed restriction. It is not clear why fine steering reversals made on the Ampthill section of the route are associated with this factor when fine steering reversals made in Marston itself are not. Factor 9 departs from the pattern seen previously in Factors 5, 6, 7 and 8, therefore, and that seen in factors 10, 11, 12, 13, 14, 15 and 16 reported below.

NFACTOR 10B "Time, coarse steer, fine steer Ampthill to Flitwick"

The highest loading variables on factor 10 were:

Variable	7	Time, Ampthill to Flitwick	+ .90
Variable	9	Coarse steer, Ampthill to Flitwick	+ .57
Variable	8	Fine steer, Ampthill to Flitwick	+ .44

A high positive score on factor 10 indicates that drivers drove slowly and made many reversals from Ampthill to Flitwick, a section of suburban driving with a 48 k/h speed restriction.

NFACTOR 11B "Time, coarse steer, fine steer Kempston roundabout, coarse steer Test Area to Ampthill"

The highest loading variables on factor 11 were:

Variable	37	Time, Kempston roundabout	+ .83
Variable	3	Coarse steer, Test Area to Ampthill	+ .44
Variable	39	Coarse steer, Kempston roundabout	+ .43
Variable	38	Fine steer, Kempston roundabout	+ .38

A high positive score on factor 11 indicates that drivers drove slowly and made many steering reversals at Kempston roundabout, a section of the route with a 48 k/h speed restriction, and made many coarse steering reversals from the Test Area to Ampthill, a trunk road section of the route with a 96 k/h speed restriction. No obvious explanation is apparent for the inclusion of variable 3 in this factor.

NFACTOR 12B "Time, coarse steer, fine steer Marston urban"

The highest loading variables on factor 12 were:

Variable 28	Time, Marston urban	+ .83
Variable 30	Coarse steer, Marston urban	+ .70
Variable 51	Fine steer, Marston urban	+ .51

A high positive score on factor 12 indicates that drivers drove slowly and made many steering reversals in Marston, a section of urban driving with a 48 k/h speed restriction.

NFACTOR 13B "Time, coarse steer, fine steer M1 to Marston"

The highest loading variables on factor 13 were:

Variable 25	Time, M1 to Marston	+ .83
Variable 27	Coarse steer, M1 to Marston	+ .62
Variable 26	Fine steer, M1 to Marston	+ .26

A high positive score on factor 13 indicates that drivers drove slowly and made many steering reversals from the M1 to Marston, a trunk road section of the route with a 96 k/h speed restriction.

NFACTOR 14B "Time, coarse steer, fine steer, Kempston to Bedford"

The highest loading variables on factor 14 were:

Variable 43	Time, Kempston to Bedford	+ .89
Variable 45	Coarse steer, Kempston to Bedford	+ .60
Variable 44	Fine steer, Kempston to Bedford	+ .34

A high positive score on factor 14 indicates that drivers drove slowly and made many steering reversals from Kempston to Bedford, a suburban section of the route with a 48 k/h speed restriction.

NFACTOR 15B "<u>Time, coarse steer, fine steer Bedford to Test Area</u>"

The highest loading variables on factor 15 were:

Variable 54	Time, Bedford to Test Area	+ .86
Variable 54	Coarse steer, Bedford to Test Area	+ .46
Variable 53	Fine steer, Bedford to Test Area	+ .23

A high positive score on factor 15 indicates that drivers drove slowly and made many steering reversals from Bedford to the Test Area, a section of trunk road with a 96 k/h speed restriction.

NFACTOR 16B "<u>Time, coarse steer, fine steer Bedford</u>"

The highest loading variables on factor 16 were:

Variable 46	Time, Bedford	+ .88
Variable 48	Coarse steer, Bedford	+ .39
Variable 47	Fine steer, Bedford	+ .28

A high positive score on factor 16 indicates that drivers drove slowly and made many steering reversals in Bedford, the longest urban section of the route with a 48 k/h speed restriction.

4.4.4 FACTOR ANALYSIS C (VARIABLES FROM TEST-TRACK 1)

The variables included in Factor Analysis C were the time, number of cones hit, number of fine steering reversals, number of coarse steering reversals and the number of subsidiary task responses made on each test-track trial (see Appendix L). The means and standard deviations for each of these variables are given in Table 3 of Appendix M, where it can be seen that a high degree of variability was associated with the 'fine steering reversals', 'time' and 'subsidiary task' variables. This is reflected in the fact that the first three factors reported below are defined exclusively in terms of one of these three variables.

The eigenvalues and percent of variance accounted for by the first seven factors derived in this analysis are given in Table 3 below.

TABLE 3 Eigenvalues, percent of variance and cumulative percent of variance accounted for by the first seven factors derived in Factor Analysis C. Data are the variables from Test-track 1.

Factor	Eigenvalue	% of Variance Accounted for	Cum.% Variance Accounted for
1	11.24	31.2	31.2
2	6.61	18.4	49.6
3	3.48	9.7	59.2
4	2.50	6.9	66.2
5	1.48	4.1	70.3
6	1.18	3.3	73.6
7	1.09	3.0	76.6

Each factor from Factor Analysis C is named, its component variables and their weights listed, and an interpretation of a high positive score on that factor is given below.

NFACTOR 1C "Fine steering reversals"

The highest loading variables on factor 1 were:

Variable 3	Fine steer, trial 1	+ .72
Variable 7	Fine steer, trial 2	+ .71
Variable 12	Fine steer, trial 3	+ .80
Variable 16	Fine steer, trial 4	+ .90
Variable 21	Fine steer, trial 5	+ .84
Variable 26	Fine steer, trial 6	+ .87
Variable 30	Fine steer, trial 7	+ .83
Variable 35	Fine steer, trial 8	+ .80

A high positive score on factor 1 indicates that drivers made many fine steering reversals on all test-track trials.

NFACTOR 2C "Time, all trials"

The highest loading variables on factor 2 were:

Variable 1	Time, trial 1	+ .91
Variable 5	Time, trial 2	+ .85
Variable 10	Time, trial 3	+ .96
Variable 14	Time, trial 4	+ .91
Variable 19	Time, trial 5	+ .95
Variable 24	Time, trial 6	+ .97
Variable 28	Time, trial 7	+ .96
Variable 33	Time, trial 8	+ .96

A high positive score on factor 2 indicates that drivers drove relatively slowly on all test-track trials.

NFACTOR 3C "Subsidiary task responses"

The highest loading variables on factor 3 were:

Variable 9	Subsidiary task, trial 2	+ .83
Variable 18	Subsidiary task, trial 4	+ .90
Variable 23	Subsidiary task, trial 5	+ .90
Variable 32	Subsidiary task, trial 7	+ .88

A high positive score on factor 3 indicates that drivers responded relatively frequently to the subsidiary task.

NFACTOR 4C "<u>Trial 2</u>"

The highest loading variables on factor 4 were:

Variable 8	Coarse steer, trial 2	+ .69
Variable 7	Fine steer, trial 2	+ .57
Variable 9	Subsidiary task, trial 2	+ .26
Variable 5	Time, trial 2	+ .25

A high positive score on factor 4 indicates that drivers made many steering reversals, drove slowly and responded frequently to the subsidiary task on trial 2. Only one variable recorded on trial 2, 'cones', is not represented in factor 4.

NFACTOR 5C "<u>Coarse steer, clockwise trials</u>"

The highest loading variables on factor 5 were:

Variable 36	Coarse steer, trial 8	+ .77
Variable 35	Fine steer, trial 8	+ .34
Variable 27	Coarse steer, trial 6	+ .26
Variable 17	Coarse steer, trial 4	+ .22
Variable 8	Coarse steer, trial 2	+ .21

A high positive score on factor 5 indicates that drivers made many coarse steering reversals on test-track trials which were run in a clockwise direction, and made many fine steering reversals on one clockwise trial, trial 8. Implicit in this interpretation of factor 5 is that a greater variability was seen in drivers' steering reversals on clockwise trials and this is confirmed by the standard deviations given in Appendix M. Some drivers did, in fact, report that it was easier to drive the course in a counter-clockwise direction, an observation which is in agreement with the interpretation of factor 5.

NFACTOR 6C "<u>Cones, trial 8</u>"

Only one variable was loaded highly on this factor, namely:

Variable 34	Cones, trial 8	+ .95

A high positive score on factor 6 indicates that drivers hit a relatively large number of cones on trial 8.

NFACTOR 7C "<u>Cones, trial 7</u>"

Only one variable was loaded highly on this factor, namely:

Variable 29	Cones, trial 7	+ .95

A high positive score on factor 7 indicates that drivers hit a relatively large number of cones on trial 7.

4.4.5 FACTOR ANALYSIS D (ITEMS FROM QUESTIONNAIRE C)

The variables included in Factor Analysis D were the items from Questionnaire C, in which subjects were asked to compare the experimental car's steering on the second road-run with the steering on Road-run 1, (see Appendix C). It should be remembered that subjects had been assigned to their respective power steering groups at this point in the experiment, so that some of the questionnaire responses analysed here were made by subjects who had driven with the experimental power steering characteristics and some were made by subjects who had driven with the standard power steering (the Control group).

The means and standard deviations of subjects' scores on each item from Questionnaire C are given in Table 4 of Appendix M, and these indicate that, in general, scores were grouped around the middle or 'neutral' category on each item. A comparison of the standard deviations given in Tables 1 and 4 of Appendix M suggest that there was less variability associated with subjects' responses to the items in Questionnaire C than with their responses to the items in Questionnaire B.

This indicates that the differences between the standard power steering and the steering of subjects' own cars (Questionnaire B) were more marked than the differences between the standard power steering and the experimental steering characteristics (Questionnaire C).

The eigenvalues and the percent of variance accounted for by the first seventeen factors derived in this analysis are given in Table 4 below.

TABLE 4. Eigenvalues, percent of variance and cumulative percent of variance accounted for by the first seventeen factors derived in Factor Analysis D. Data are the items from Questionnaire C in which subjects compared the experimental car's steering on the second road-run with the steering on Road-run 1.

Factor	Eigenvalue	% of Variance Accounted for	Cum.% Variance Accounted for
1	19.39	27.3	27.3
2	4.35	6.1	33.4
3	3.62	5.1	38.5
4	3.28	4.6	43.1
5	2.84	4.0	47.1
6	2.15	3.0	50.2
7	1.98	2.8	53.0
8	1.97	2.8	55.7
9	1.82	2.6	58.3
10	1.69	2.4	60.7
11	1.61	2.3	63.0
12	1.55	2.2	65.1
13	1.38	1.9	67.1
14	1.34	1.9	69.0
15	1.30	1.8	70.8
16	1.19	1.7	72.5
17	1.14	1.6	74.1

Each factor from Factor Analysis D is named, its highest loading variables and their weights listed, and an interpretation of a high positive score on that factor is given below.

NFACTOR 1D "<u>Difficult to judge effort required, tendency to oversteer, difficult to get used to</u>"

The highest loading variables on factor 1 were:

Item 26	Difficult to judge effort entering roundabout	+ .81
Item 10	Tendency to oversteer	+ .77
Item 11	Difficult to judge effort right angle turns	+ .74
Item 36	Difficult to judge effort on sharp bends	+ .75
Item 5	Easy to get used to	- .69
Item 19	Confidence in steering	- .63
Item 45	Having to think about the steering	+ .62
Item 62	Degree of control over the car	- .60
Item 55	Number of corrective steering movements	+ .50
Item 35	Difficulty in positioning the car on bends	+ .47

A high positive score on factor 1 indicates that drivers found it difficult to judge the amount of effort required to steer the car under normal urban driving conditions, found that they tended to oversteer, found the steering difficult to get used to, lacked confidence in the steering, had to think about the steering, felt that they had little control over the car and made many corrective steering movements. Although there are fewer 'positioning' variables associated with this factor, it is very similar to the first factor derived in Factor Analysis A (Questionnaire B data).

NFACTOR 2D "Difficult to maintain lane position, difficult to control during lane changes, lack of confidence at high speed"

The highest loading variables on factor 2 were:

Item 54	Difficult to maintain lane position at high speeds on the motorway	+ .81
Item 53	Difficult to maintain lane position at moderate speeds on the motorway	+ .80
Item 52	Difficult to control when changing lanes at high speed on the motorway	+ .77
Item 29	Difficult to position on straight roads	+ .72
Item 51	Difficult to control when changing lanes at moderate speeds on the motorway	+ .69
Item 28	Easy to keep on course over uneven roads	- .67
Item 34	Confidence at high speeds	- .53
Item 55	Number of corrective steering movements	+ .51
Item 56	Difficult to tell how much grip between the front wheels and road	+ .49
Item 62	Degree of control over the car	- .45

A high positive score on factor 2 indicates that drivers had difficulty in keeping the car on course in straight-line driving, found it difficult to control the car when changing lanes, and lacked confidence at speed. Factor 2 from the present analysis corresponds very closely with the second factor from Factor Analysis A (Questionnaire B data).

NFACTOR 3D "Willingness to manoeuvre the car and to steer precisely"

The highest loading variables on factor 3 were:

Item 27	Willingness to 'nip in and out' around parked vehicles	+ .69
Item 15	Likelihood of squeezing past slow moving vehicles	+ .63
Item 43	Likelihood of entering small gaps in the traffic	+ .63
Item 39	Likelihood of crossing the white line on bends	- .63
Item 17	Likelihood of steering around a pedestrian	+ .62
Item 48	Cutting corners, major to minor road	- .52
Item 50	Likelihood of accepting small gaps in traffic on the motorway	+ .49
Item 67	Feeling relaxed in the car	+ .48
Item 20	Difficult to position the car entering a roundabout	- .39
Item 48	Difficult to tell when the wheels are straight ahead	- .38

A high positive score on factor 3 indicates that drivers were willing to make precise steering manoeuvres in the car, were less likely to cut corners, felt more relaxed, found it easier to position the car at roundabouts, and found it easier to judge when the wheels were in the straight ahead position. Factor 3 corresponds very closely to the third factor from Factor Analysis A (Questionnaire B data).

NFACTOR 4D "Favourable reaction to the lightness of the steering, feeling more relaxed"

The highest loading variables on factor 4 were:

Item 7	Lightness of the steering at parking speeds	+ .84
Item 21	(As above, duplicated item)	+ .80
Item 65	Lightness of the steering overall	+ .74
Item 31	Lightness of steering at moderate to high speeds	+ .56
Item 33	More effort required when driving slowly than when driving fast	- .53
Item 67	Feeling relaxed in the car	+ .31

A high positive score on factor 4 indicates that drivers found the steering light at all speeds but especially when parking, found that less effort was required when driving slowly than when driving fast, and that drivers felt more relaxed in the car this time. Factor 4 corresponds closely to factor 6 from Factor Analysis A (Questionnaire B data).

NFACTOR 5D "Driving faster, overtaking more frequently"

The highest loading variables on factor 5 were:

Item 37	Driving faster on straight roads	+ .81
Item 40	Frequency of overtaking	+ .77
Item 60	Driving faster overall	+ .78
Item 38	Driving faster through bends	+ .46
Item 42	Difficult to position the car when changing lanes to pass another vehicle	- .26
Item 51	Difficult to control when changing lanes at moderate speeds on the motorway	- .25

A high positive score on factor 5 indicates that drivers felt that they drove faster and overtook more frequently in the car on the second road-run, and found it easier to control the lateral position of the car when changing lanes in traffic and at moderate speeds on the motorway. No equivalent of factor 5 was found in the analysis of data from Questionnaire B which suggests that this factor was generated by subjects' increased familiarity with the car on the second road-run.

NFACTOR 6D "Close manoeuvering, easier to position"

The highest loading variables on factor 6 were:

Item 14	Returning to the lane earlier having passed a parked vehicle	+ .73
Item 12	Moving out earlier when passing parked vehicles	- .54
Item 22	Likelihood of forming second queue at traffic lights	+ .44
Item 9	Difficult to position on right angle turns	- .43
Item 35	Difficult to position on bends	- .41
Item 20	Difficult to position entering roundabout	- .40
Item 13	Passing close alongside stationary vehicles	+ .34
Item 70	Driving more safely	- .27

A high positive score on factor 6 indicates that drivers felt that they passed closer to parked vehicles and found that they could position the car accurately. Interestingly, a high positive score also implies that drivers felt they were driving less safely on the second road-run. Again, factor 6 has no equivalent in the analysis of Questionnaire B data, so that it seems to have been generated as a result of drivers' increased familiarity with the car.

NFACTOR 7D "Having less to do because of the brakes and transmission"

The highest loading variables on factor 7 were:

Item 59	Having less to do because of the brakes	+ .86
Item 58	Having less to do because of the transmission	+ .83
Item 71	More confidence at low speeds than at high speeds	+ .32
Item 39	Likelihood of crossing the white line on bends	- .27
Item 69	Willingness to park on other side of road	+ .25
Item 31	Lightness of steering, moderate to high speeds	- .23

A high positive score on factor 7 indicates that drivers felt they had less to do because of the power brakes and the automatic transmission, felt more confident about the steering at low speeds than at high speeds, thought that the steering was heavier at moderate to high speeds, felt that they were less likely to cross the white line on bends and more likely to park on the other side of the road. Factor 7 is similar to factor 8 from Factor Analysis A (Questionnaire B data). When considering the interpretation of this factor, it is important to bear in mind the subjective nature of responses to items 5 and 59. In Questionnaire C, on which the present analysis was based, subjects were comparing the car on the second road-run with the car on the first road-run. Since no real differences existed in the non-steering components of the car between the two road-runs, 'having less to do' was the result of increased familiarity with the car rather than any mechanical changes to the brakes or transmission.

NFACTOR 8D "Steering too light and no different"

The highest loading variables on factor 8 were:

Item 64	Steering too light overall	+ .82
Item 32	Steering too light at moderate to high speeds	+ .58
Item 18	Steering too light at low speeds	+ .42
Item 28	Easy to keep on course over uneven roads	+ .36
Item 1	Steering different	- .26
Item 63	Becoming more frustrated	- .25

A high positive score on factor 8 indicates that drivers felt that the steering was too light and, although they were less frustrated and found it easier to keep the car on course over uneven roads, felt that the steering was no different. Factor 8 is similar to factor 5 from the analysis of Questionnaire B except that the 'lack of confidence' variable is no longer present. In other words, although drivers found that the steering was too light, this was not affecting their confidence on Road-run 2.

NFACTOR 9D "Holding back less, lack of 'feel', more confidence at high speed than at low speed"

The highest loading variables on factor 9 were:

Item 16	Holding back more often	- .79
Item 49	Difficult to tell how much grip between the front wheels and the road	+ .70
Item 71	More confidence at low speed than at high speed	- .31
Item 40	Overtaking more often	+ .26
Item 18	Steering too light at low speed	+ .25
Item 46	Cutting corners, major to minor roads	+ .22
Item 48	Difficult to judge when wheels are straight ahead	+ .21

A high positive score on factor 9 indicates that drivers felt that they held back less often, found it difficult to tell how much grip there was between the front wheels and the road, felt less confident at low speeds than at high speeds, thought that they overtook more often, felt that the steering was too light at low speeds, thought they cut corners more, and found it difficult to judge when the wheels were straight ahead. Whilst commenting on the lack of 'feel' at low speeds, therefore, (items 48 and 49) high scoring drivers thought that they held back less and overtook more on the second road-run.

NFACTOR 10D "Sensitivity, responsiveness, easy to position"

The highest loading variables on factor 10 were:

Item 3	Sensitivity of the steering in the straight ahead position	+ .80
Item 2	Speed of response of the steering	+ .56
Item 12	Moving out earlier when passing a parked vehicle	- .32
Item 35	Difficult to position on bends	- .25
Item 42	Difficult to position when changing lanes to pass another vehicle	- .23
Item 20	Difficult to position car entering a roundabout	- .22

A high positive score on factor 10 indicates that drivers found the steering sensitive and quick to respond, and that they found it easy to position the car laterally (items 35 and 42) and longitudinally (item 12).

NFACTOR 11D "Having less to do, steering different, driving more aggressively"

The highest loading variables on factor 11 were:

Item 57	Having less to do because of the steering	+ .80
Item 1	Steering different	+ .53
Item 13	Passing close alongside stationary vehicles	+ .40
Item 66	Driving more aggressively	+ .28
Item 56	Having more to do	- .26

A high positive score on factor 11 indicates that drivers felt they had less to do because of the steering, felt that the steering was different, felt that they passed closer alongside stationary vehicles and that they drove more aggressively.

NFACTOR 12D "Confidence in the steering"

The highest loading variables on factor 12 were:

Item 30	Confidence in the steering at moderate speeds	+ .57
Item 34	Confidence in the steering at high speeds	+ .49
Item 41	Confidence in the steering when overtaking	+ .43
Item 19	Confidence in the steering	+ .38
Item 27	Willingness to 'nip in and out' around parked vehicles	+ .26
Item 56	Having more to do	- .26
Item 28	Easy to keep on course over uneven roads	+ .24

A high positive score on factor 12 indicates that drivers felt more confident about all aspects of the car's steering on Road-run 2, felt more willing to 'nip in and out' around parked vehicles, felt that they had less to do, and found the car easier to keep on course over uneven roads.

NFACTOR 13D "Feeling more alert and anticipatory due to sudden changes in effort"

The highest loading variables on factor 13 were:

Item 68	Feeling more alert in the car	+ .83
Item 44	More sudden changes in the amount of effort required to steer the car	+ .42
Item 56	Having more to do	+ .31
Item 22	Likelihood of forming second queue at the traffic lights	+ .28
Item 66	Driving more aggressively	+ .26
Item 45	Having to think about the steering	+ .25

A high positive score on factor 13 indicates that drivers felt more alert in the car on Road-run 2, noticed more sudden changes in the amount of effort required to steer the car, felt that they had more to do, had to think about the steering, were more likely to form a second queue at the traffic lights and thought that they drove more aggressively. Factor 13 is similar to factor 11 from the analysis of data from Questionnaire B in that 'feeling alert' is associated with difficulties with the steering. Unlike the earlier factor, however, factor 13 is also associated with a feeling of driving more aggressively.

NFACTOR 14D "Less willing to wait at mini-roundabouts, driving more aggressively"

The highest loading variables on factor 14 were:

Item 23	Willingness to wait one's turn at mini-roundabouts	- .83
Item 66	Driving more aggressively	+ .43
Item 15	Likelihood of squeezing past parked vehicles	+ .35
Item 1	Steering different	- .30
Item 63	Becoming more frustrated	+ .27
Item 43	Likelihood of entering small gaps in the traffic	+ .26
Item 50	Willingness to enter small gaps in the traffic on the motorway	+ .22

A high positive score on factor 14 indicates that drivers were less willing to wait their turn at mini-roundabouts, felt that they were driving more aggressively, felt more frustrated, were more likely to accept small gaps in the traffic and thought that the steering was no different on Road-run 2. This factor is in contrast with factor 9 from this analysis which is concerned with a bolder and more aggressive driving style at high speeds. A high score on the present factor indicates a tendency to drive aggressively in urban traffic situations.

NFACTOR 15D "More effort required when cornering hard, feeling more frustrated"

The highest loading variables on factor 15 were:

Item 47	Effort greater when cornering hard than when cornering gently	+ .75
Item 63	Becoming more frustrated	+ .33
Item 50	Willingness to accept small gaps in the traffic on the motorway	- .33
Item 36	Difficult to judge effort on sharp bends	+ .29
Item 46	Cutting corners, major to minor roads	+ .28
Item 61	Driving more smoothly	- .25
Item 31	Lightness of the steering moderate to high speeds	- .24

A high positive score on factor 15 indicates that drivers felt that more effort was required to steer the car when cornering hard than when cornering gently, felt more frustrated driving the car, were less willing to accept small gaps on the motorway, found it more difficult to judge how much effort was required to steer the car on sharp bends, tended to cut corners when turning into a minor road and found the steering heavier at moderate to high speeds. It is likely that drivers' responses to particular power steering characteristics are reflected in factor 15. The presence of item 47, for example, is particularly appropriate to the unique properties of the Conventional Reaction system.

NFACTOR 16D "Less play in the steering, taking longer at mini-roundabouts"

The highest loading variables on factor 16 were:

Item 6	Amount of play in the steering	- .67
Item 24	Time taken to negotiate mini-roundabout	+ .39
Item 25	Time taken to enter mini-roundabout	+ .39
Item 13	Passing close alongside stationary vehicles	+ .36
Item 70	Driving more safely	- .31
Item 5	Easier to get used to	+ .27

A high positive score on factor 16 indicates that drivers thought there was less play in the steering, felt that they took longer to negotiate mini-roundabouts, thought that they passed closer alongside stationary vehicles, felt that they drove less safely and that the steering was easier to get used to. The relationship between item 6 and the other variables associated with factor 16 is not clear.

NFACTOR 17D "Forcefulness of return to straight ahead position, confidence at low speeds, steering too light at higher speeds"

The highest loading variables on factor 17 were:

Item 8	Forcefulness of return to straight ahead	+ .82
Item 32	Steering too light at moderate to high speeds	+ .37
Item 71	More confidence at low than at high speeds	+ .32
Item 33	Effort greater when driving slowly than when driving fast	- .28
Item 25	Time taken to enter mini-roundabout	- .25
Item 48	Difficult to judge when wheels are straight ahead	- .24

A high positive score on factor 17 indicates that drivers found that the steering returned forcefully to the straight ahead position, felt that the steering was too light at high speeds, were more confident in the steering at low speeds than at high speeds, found that less effort was required to steer the car when driving slowly than when driving fast, felt that they took less time to enter a mini-roundabout and found it easier to judge when the wheels were straight ahead. Factor 17 contrasts with factor 9 in which high scores were associated with greater confidence at high speeds than at low speeds and a lack of steering 'feel'.

4.4.6 FACTOR ANALYSIS E (VARIABLES FROM ROAD-RUN 2)

The variables included in Factor Analysis E were the time, the number of fine steering reversals, and the number of coarse steering reversals recorded on each of the eighteen sections of the route, (see Appendix K). The means and standard deviations of these variables are given in Table 5 of Appendix M, where it can be seen that the 'fine steering reversals' variable was associated with relatively more variability than the 'coarse steering reversals' and 'time' variables. This was also noted in the factor analysis of Road-run 1 data reported previously, and again the first factor derived in the present analysis is exclusively related to the number of fine steering reversals made on each section of the route.

The eigenvalues, percent of variance accounted for and cumulative percent of variance accounted for by the first fifteen factors from this analysis are given in Table 5 below:

TABLE 5 Eigenvalues, percent of variance and cumulative percent of variance accounted for by the first fifteen factors derived in Factor Analysis E. Data are the variables from Road-run 2.

Factor	Eigenvalue	% of Variance Accounted for	Cum. % Variance Accounted for
1	14.22	26.3	26.3
2	3.64	6.7	33.1
3	3.54	6.6	39.6
4	2.58	4.8	44.4
5	2.41	4.5	48.9
6	2.09	3.9	52.8
7	1.92	3.5	56.3
8	1.70	3.1	59.5
9	1.58	2.9	62.4
10	1.52	2.8	65.2
11	1.44	2.7	67.9
12	1.28	2.4	70.2
13	1.26	2.3	72.6
14	1.16	2.2	74.7
15	1.07	2.0	76.7

Each factor from Factor Analysis E is named, its component variables and their weights listed, and an interpretation of a high positive score on that factor is given below.

NFACTOR iE "Fine steering reversals"

The highest loading variables on factor 1 were:

Variable 2	Fine steer, Test Area to Ampthill	+	.81
Variable 5	Fine steer, Ampthill	+	.76
Variable 8	Fine steer, Ampthill to Flitwick	+	.84
Variable 11	Fine steer, Flitwick	+	.82
Variable 14	Fine steer, Flitwick to Westoning	+	.80
Variable 17	Fine steer, Westoning	+	.72
Variable 20	Fine steer, Westoning to M1	+	.92
Variable 23	Fine steer, M1	+	.88
Variable 26	Fine steer, M1 to Marston	+	.86
Variable 29	Fine steer, Marston urban	+	.78
Variable 32	Fine steer, Marston suburban	+	.78
Variable 35	Fine steer, Marston to Kempston	+	.86
Variable 38	Fine steer, Kempston roundabout	+	.76
Variable 41	Fine steer, Kempston	+	.72
Variable 44	Fine steer, Kempston to Bedford	+	.76
Variable 47	Fine steer, Bedford	+	.76
Variable 50	Fine steer, Bedford Ampthill Road	+	.76
Variable 53	Fine steer, Bedford to Test Area	+	.83

A high positive score on factor 1 indicates that drivers made many fine steering reversals on each section of the route. This factor is identical to the first factor derived in Factor Analysis B (Road-run 1 data).

NFACTOR 2E "Coarse steer, M1 and trunk roads"

The highest loading variables on factor 2 were:

Variable 27	Coarse steer, M1 to Marston	+ .74
Variable 24	Coarse steer, M1	+ .72
Variable 21	Coarse steer, Westoning to M1	+ .61
Variable 6	Coarse steer, Ampthill	+ .36
Variable 9	Coarse steer, Ampthill to Flitwick	+ .35
Variable 54	Coarse steer, Bedford to Test Area	+ .34
Variable 3	Coarse steer, Test Area to Ampthill	+ .31

A high positive score on factor 2 indicates that drivers made many coarse steering reversals on a variety of different types of road but especially on straight, 'fast' roads. Factor 2 is similar to the second factor derived in the analysis of Road-run 1 data (Factor Analysis B), except that the emphasis has changed from coarse steering reversals on suburban and trunk roads to coarse steering reversals on the motorway and trunk roads in the present analysis.

NFACTOR 3E "<u>Time, coarse steer, fine steer Kempston to Bedford and Bedford</u>"

The highest loading variables on factor 3 were:

Variable 43	Time, Kempston to Bedford	+ .86
Variable 45	Coarse steer, Kempston to Bedford	+ .59
Variable 44	Fine steer, Kempston to Bedford	+ .45
Variable 46	Time, Bedford	+ .38
Variable 47	Fine steer, Bedford	+ .33
Variable 48	Coarse steer, Bedford	+ .32

A high positive score on factor 3 indicates that drivers drove slowly and made many steering reversals from Kempston to Bedford, a suburban section of the route with a 48 k/h speed restriction, and, to a lesser extent, drove slowly and made many steering reversals in Bedford, an urban section of the route with a 48 k/h speed restriction.

NFACTOR 4E "Time, Marston. Coarse steer, Test Area to Ampthill. Time and coarse steer, Bedford Ampthill Road"

The highest loading variables on factor 4 were:

Variable 31	Time, Marston suburban	+ .84
Variable 3	Coarse steer, Test Area to Ampthill	+ .78
Variable 51	Coarse steer, Bedford Ampthill Road	+ .52
Variable 49	Time, Bedford Ampthill Road	+ .49

A high positive score on factor 4 indicates that drivers drove slowly in the suburban part of Marston, made many coarse steering wheel reversals from the Test Area to Ampthill, a trunk road section of the route, and drove slowly making many coarse steering reversals in Bedford Ampthill Road, a suburban section of the route with a 48 k/h speed restriction. The nature of the relationship between the variables associated with factor 4 is not at all clear. Factor 4 is uninterpretable, therefore.

NFACTOR 5E "Time, coarse steer, fine steer Kempston. Time, coarse steer Bedford"

The highest loading variables on factor 5 were:

Variable 40	Time, Kempston	+ .88
Variable 42	Coarse steer, Kempston	+ .50
Variable 46	Time, Bedford	+ .48
Variable 41	Fine steer, Kempston	+ .45
Variable 48	Coarse steer, Bedford	+ .32

A high positive score on factor 5 indicates that drivers drove slowly and made many steering reversals in Kempston, and drove slowly and made many coarse steering reversals in Bedford, both urban sections of the route with 48 k/h speed restrictions.

NFACTOR 6E "<u>Time, coarse steer, fine steer Ampthill</u>"

The highest loading variables on factor 6 were:

Variable 4	Time, Ampthill	+ .83
Variable 6	Coarse steer, Ampthill	+ .62
Variable 5	Fine steer, Ampthill	+ .51

A high positive score on factor 6 indicates that drivers drove slowly and made many steering reversals in Ampthill. The relationship between variables 4, 6 and 5 and factor 6 repeats the pattern seen frequently in the factors derived in the analysis of Road-run 1 data, that is, time, coarse steering reversals and fine steering reversals in descending order of importance.

NFACTOR 7E "<u>Driving fast and making many coarse steering reversals</u>"

The highest loading variables on factor 7 were:

Variable 34	Time, Marston to Kempston	- .79
Variable 15	Coarse steer, Flitwick to Westoning	+ .43
Variable 51	Coarse steer, Bedford Ampthill Road	+ .42
Variable 31	Time, Marston suburban	- .25
Variable 6	Coarse steer, Ampthill	+ .23
Variable 4	Time, Ampthill	- .22

A high positive score on factor 7 indicates that drivers drove relatively quickly on various sections of the route, especially from Marston to Kempston, and made many coarse steering reversals on some sections of the route. Factor 7 is unique in that it combines short driving times with high numbers of coarse steering reversals. The pattern normally seen is that of time and coarse steer being positively rather than negatively related.

NFACTOR 8E "Time, coarse steer, fine steer Kempston"

The highest loading variables on factor 8 were:

Variable 37	Time, Kempston	+ .90
Variable 39	Coarse steer, Kempston	+ .66
Variable 38	Fine steer, Kempston	+ .40

A high positive score on factor 8 indicates that drivers drove relatively slowly and made many steering reversals in Kempston, an urban section of the route with a 48 k/h speed restriction. Factor 8 corresponds very closely to factor 4 derived in Factor Analysis B (Road-run 1 data).

NFACTOR 9E "Time, coarse steer, fine steer Bedford to Test Area"

The highest loading variables on factor 9 were:

Variable 52	Time, Bedford to Test Area	+ .83
Variable 54	Coarse steer, Bedford to Test Area	+ .68
Variable 53	Fine steer, Bedford to Test Area	+ .26

A high positive score on factor 9 indicates that drivers drove slowly and made many steering reversals from Bedford to the Test Area, a section of trunk road with a 96 k/h speed restriction. Factor 9 corresponds closely to factor 15 from Factor Analysis B (Road-run 1 data).

NFACTOR 10E. "Time, Flitwick to Westoning. Time, Westoning"

The highest loading variables on factor 10 were:

Variable 13	Time, Flitwick to Westoning	+ .87
Variable 16	Time, Westoning	+ .38
Variable 45	Coarse steer, Kempston to Bedford	- .28
Variable 15	Coarse steer, Flitwick to Westoning	+ .27

A high positive score on factor 10 indicates that drivers drove slowly from Flitwick to Westoning and in Westoning, a rural section and an urban section of the route respectively, and made many coarse steering reversals from Flitwick to Westoning. The importance of the first two variables on this factor, slow driving times on two adjoining sections of the route, may be explained in terms of the variability in drivers' speeds on these sections. The presence of many heavy goods vehicles on these sections of the route (these vehicles were heading for the motorway), and the inability of drivers to overtake due to the high number of curves, meant that drivers' speed was governed by the presence or absence of slow moving traffic. If the driver found himself behind a slow moving vehicle, therefore, he had no choice but to drive slowly. If the driver was not held up by slow moving traffic, however, he was able to drive relatively quickly on this section of the route. A high variability in driving speed resulted from this situation and this appears to be reflected in factor 10.

NFACTOR 11E "Coarse steer, time, fine steer Westoning"

The highest loading variables on factor 11 were:

Variable 18	Coarse steer, Westoning	+ .86
Variable 16	Time, Westoning	+ .59
Variable 12	Coarse steer, Flitwick	+ .39
Variable 17	Fine steer, Westoning	+ .25

A high positive score on factor 11 indicates that drivers made many steering reversals and drove slowly in Westoning, an urban section of the route with a 48 k/h speed restriction, and made many coarse steering reversals in Flitwick, an urban section of the route with a 48 k/h speed restriction.

NFACTOR 12E "<u>Time, coarse steer, fine steer Flitwick</u>"

The highest loading variables on factor 12 were:

Variable 10	Time, Flitwick	+ .87
Variable 12	Coarse steer, Flitwick	+ .60
Variable 11	Fine steer, Flitwick	+ .35

A high positive score on factor 12 indicates that drivers drove slowly and made many steering reversals in Flitwick, an urban section of the route with a 48 k/h speed restriction. Factor 12 corresponds closely to factor 7 derived in Factor Analysis B (Road-run 1 data).

NFACTOR 13E "<u>Slow drivers</u>"

The highest loading variables on factor 13 were:

Variable 25	Time, M1 to Marston	+ .85
Variable 22	Time, M1	+ .50
Variable 46	Time, Bedford	+ .32
Variable 34	Time, Marston to Kempston	+ .27
Variable 49	Time, Bedford Ampthill Road	+ .23

A high positive score on factor 13 indicates that drivers drove slowly on the motorway, trunk roads, urban and sub-urban sections of the route.

NFACTOR 14E "<u>Time, coarse steer, fine steer Ampthill to Flitwick</u>"

The highest loading variables on factor 14 were:

Variable 7	Time, Ampthill to Flitwick	+ .88
Variable 9	Coarse steer, Ampthill to Flitwick	+ .67
Variable 8	Fine steer, Ampthill to Flitwick	+ .32

A high positive score on factor 14 indicates that drivers drove slowly and made many steering reversals from Ampthill to Flitwick, a suburban section of the route with a 48 k/h speed restriction. Factor 14 corresponds closely to factor 10 from Factor Analysis B (Road-run 1 data).

NFACTOR 15E "Time, coarse steer, fine steer Westoning to the M1"

The highest loading variables on factor 15 were:

Variable 19	Time, Westoning to the M1	+ .93
Variable 21	Coarse steer, Westoning to the M1	+ .52
Variable 16	Time, Westoning	+ .34
Variable 20	Fine steer, Westoning to the M1	+ .20

A high positive score on factor 15 indicates that drivers drove slowly and made many steering reversals from Westoning to the M1, a trunk road section of the route with a 96 k/h speed restriction, and drove slowly through Westoning, an urban section of the route with a 48 k/h speed restriction.

4.4.7 FACTOR ANALYSIS F (VARIABLES FROM TEST-TRACK 2)

The variables included in Factor Analysis F were the time, number of cones hit, number of fine steering reversals, number of coarse steering reversals and the number of subsidiary task responses made on each test-track trial, (see Appendix L). The means and standard deviations of each of these variables are given in Table 6 of Appendix M, where it can be seen that a relatively high degree of variability was associated with the 'steering reversals', 'time' and 'subsidiary task' variables. This is reflected in the fact that the first three factors reported below are defined in terms of these variables.

The eigenvalues, percent of variance and cumulative percent of variance accounted for by the first seven factors derived in this analysis are given in Table 6 below.

TABLE 6. Eigenvalues, percent of variance and cumulative percent of variance accounted for by the first seven factors derived in Factor Analysis F. Data are from Test-track 2.

Factor	Eigenvalue	% of Variance Accounted for	Cum. % Variance Accounted for
1	9.89	27.5	27.5
2	7.71	21.4	48.9
3	3.32	9.2	58.1
4	2.62	7.3	65.4
5	1.45	4.0	79.4
6	1.10	3.1	72.5
7	1.00	2.8	75.3

Each factor from Factor Analysis F is named, its component variables and their weights listed, and an interpretation of a high positive score on that factor is given below.

NFACTOR 1F "Steering reversals"

The highest loading variables on factor 1 were:

Variable 7	Fine steer, trial 2	+ .86
Variable 16	Fine steer, trial 4	+ .86
Variable 26	Fine steer, trial 6	+ .85
Variable 35	Fine steer, trial 8	+ .83
Variable 30	Fine steer, trial 7	+ .82
Variable 12	Fine steer, trial 3	+ .81
Variable 21	Fine steer, trial 5	+ .76
Variable 3	Fine steer, trial 3	+ .71
Variable 22	Coarse steer, trial 5	+ .60
Variable 27	Coarse steer, trial 6	+ .57
Variable 8	Coarse steer, trial 2	+ .54
Variable 31	Coarse steer, trial 7	+ .52
Variable 13	Coarse steer, trial 3	+ .50
Variable 17	Coarse steer, trial 4	+ .49
Variable 36	Coarse steer, trial 8	+ .46
Variable 4	Coarse steer, trial 1	+ .32

A high positive score on factor 1 indicates that drivers made many steering reversals on all trials. Whereas in the analysis of Test-track 1 data (Factor Analysis C), fine steering reversals and coarse steering reversals were associated with separate factors, in the present analysis, both fine and coarse steering reversals are associated with factor 1. The relatively greater importance of fine steering reversals, however, and the greater importance of reversals made on clockwise trials which was seen in Factor Analysis C, is also reflected by the weights attached to these variables in the present analysis.

NFACTOR 2F "Time, all trials"

The highest loading variables on factor 2 were:

Variable 10	Time, trial 3	+ .96
Variable 33	Time, trial 8	+ .95
Variable 28	Time, trial 7	+ .92
Variable 1	Time, trial 1	+ .92
Variable 19	Time, trial 5	+ .91
Variable 5	Time, trial 2	+ .90
Variable 14	Time, trial 4	+ .85
Variable 24	Time, trial 6	+ .84

A high positive score on factor 2 indicates that drivers drove slowly on all test-track trials. Factor 2 corresponds closely with the second factor derived in Factor Analysis C (Test-track 1 data).

NFACTOR 3F "Subsidiary task responses"

The highest loading variables on factor 3 were:

Variable 23	Subsidiary task, trial 5	+ .94
Variable 32	Subsidiary task, trial 7	+ .93
Variable 18	Subsidiary task, trial 4	+ .91
Variable 9	Subsidiary task, trial 2	+ .88

A high positive score on factor 3 indicates that drivers made many subsidiary task responses on all trials on which the task was administered.

NFACTOR 4F "Steering reversals, trial 1 and trial 3"

The highest loading variables on factor 4 were:

Variable 4	Coarse steer, trial 1	+ .87
Variable 3	Fine steer, trial 1	+ .47
Variable 12	Fine steer, trial 3	+ .26
Variable 8	Coarse steer, trial 2	+ .24
Variable 13	Coarse steer, trial 3	+ .22

A high positive score on factor 4 indicates that drivers made many steering reversals on trials 1 and 3. The most important of these variables was coarse steering reversals on trial 1, however, which was the least prominent of the fine and coarse steering reversals variables associated with factor 1.

NFACTOR 5F "Cones, trial 3"

Only one variable was loaded highly on this factor, namely:

Variable 11	Cones, trial 3	+ .94

A high positive score on factor 5 indicates that drivers hit a relatively large number of cones on trial 3.

NFACTOR 6F "Cones, trial 1"

Only one variable was loaded highly on this factor, namely:

Variable 2	Cones, trial 1	+ .94

A high positive score on factor 6 indicates that drivers hit a relatively large number of cones on trial 1.

NFACTOR 7F "Cones, trial 8"

Only one variable was loaded highly on this factor, namely:

Variable 34	Cones, trial 8	+ .91

A high positive score on factor 7 indicates that drivers hit a relatively large number of cones on trial 8.

4.4.8 INTRODUCTION TO DISCRIMINANT ANALYSIS

A total of forty two NFactors were extracted from the principal components analysis of Questionnaire 'B', Road-run 1, and Test-track 1 data, and a further thirty nine NFactors were extracted from the principal components analysis of Questionnaire 'C', Road-run 2 and Test-track 2 data. The third and final stage in the multivariate analysis of the results from the study involved the use of discriminant analysis in an attempt to discriminate between the experimental groups on the basis of these NFactors. A series of discriminant analyses was performed, therefore, using the same version of the SPSS package as was used previously for the principal components analyses, and run on the same computer at the University of Manchester Regional Computer Centre.

Discriminant analysis seeks to provide one or more discriminant functions, each function being a linear combination of the variables entered into the analysis, on which the experimental groups' scores are maximally separated. In this case, the discriminant variables were the NFactors from the previous analyses. Ideally, a single function is sought on which the scores within individual groups are clustered at widely separated intervals. The maximum number of discriminant functions extracted in a discriminant analysis is the number of groups minus one, or the number of variables entered, whichever is the smaller. Very often, however, some functions are found to increase the ability to discriminate between the experimental groups only slightly, so that fewer than the maximum number of functions will account for virtually all of the available discriminating power. Each of the discriminant functions extracted is orthogonal, or statistically unrelated, to each of the other discriminant functions.

The SPSS subprogram "Discriminant" provides six different methods of entering variables into the analysis. One of these is a 'direct' method in which all variables are included, and the remaining five methods involve 'stepwise' procedures. The advantage of the 'stepwise' methods is that only those discriminant variables which contribute significantly to the ability to separate groups are included in the analysis. The stepwise method chosen for the discriminant analyses reported here selects or rejects variables on the basis of their increasing or decreasing Rao's V when added to previously selected variables. Rao's V provides a measure of the separation between groups, and variables which increase V only marginally, or actually decrease the value of V when added to previous variables, are therefore rejected.

Irrespective of the particular stepwise procedure chosen, variables are initially selected for inclusion in the analysis on the basis of their univariate F ratios. That is to say, an F test is performed on each variable prior to its evaluation on the stepwise entry criterion, and if the obtained value of F is too small, that variable is not considered for inclusion. The default value for minimum F, used for all the analyses reported here, is set so that almost any variable with some discriminatory power will be retained. Of those variables selected for inclusion on the basis of their univariate F ratios, that variable with the largest F is entered on the first step of the stepwise procedure. The results of these univariate F tests are often of interest in their own right, since they indicate whether or not the differences between groups on a particular variable are significant, and this can aid the interpretation of the discriminant functions derived. For each discriminant analysis reported below, those discriminant variables for which significant F ratios were obtained are indicated and referred to in the text where this assists the interpretation of results.

The output from subprogram 'Discriminant' provides a number of measures which indicate the relative importance of the individual variables and the relative importance of the discriminant functions in discriminating between the experimental groups. The relative importance of each discriminant variable to a given function is indicated by the magnitude of its standardized weighting coefficient. The sign of the standarddized weighting coefficient indicates whether the variable makes a positive or negative contribution to the function. The eigenvalue associated with each discriminant function indicates the amount of variance in the discriminant variables accounted for by that function. The sum of the eigenvalues represents the total amount of variance accounted for by all the discriminant functions. The relative importance of each function is indicated by the percent of trace which represents the proportion of the total variance, or sum of the eigenvalues, which is accounted for by an individual function. The canonical correlation provides a further index of the importance of a function and is analogous to the correlation ratio in a one-way analysis of variance. If the experimental groups are thought of as representing the various levels of the independent variable in a one-way analysis of variance, the canonical correlation coefficient squared may be taken as an index of the amount of variance in the scores on a particular function which is accounted for by the 'experimental groups' variable. Wilk's Lambda provides an inverse measure of the discriminating power left in the original variables after that accounted for by each function has been removed. That is to say, the larger the value of Lambda, the less discriminating power remains. Lambda is transformed into a Chi-square statistic to provide a statistical test of the significance of the remaining discriminating power. When the value of Lambda is sufficiently large that its associated Chi-square statistic fails to reach significance, further functions cannot contribute to the ability to discriminate between the experimental groups, and may, therefore, be ignored. Finally, the output from subprogram 'Discriminant' also includes a classification matrix which indicates the accuracy with which group membership can be predicted on the basis of the discriminant functions derived. The classification matrix takes the form of the percentage of known group members which is correctly classified as belonging to that particular experimental group. A comparison of the predicted group membership with actual group membership provides a further index of the adequacy of the discriminant functions extracted in the analysis. A Chi-square test of significance is performed on the overall percentage of cases correctly classified in each analysis.

A total of sixteen discriminant analyses were performed on the NFactors derived from the previous principal components analyses, and their results are summarized in Table 7 below. It can be seen from Table 7 that the NFactors derived from Questionnaire 'B', Road-run 1 and Test-track 1 were used as the discriminant variables in the first four analyses, and that subjects were classified only on the basis of sex to provide two experimental groups, males and females. Since there were only two experimental groups in these analyses, a single discriminant function was extracted in each, and these were all found to be significant at the 1% level. When the NFactors from all three data sources were combined in Discriminant Analysis 4, 91% of subjects could be correctly classified as male or female on the basis of the discriminant function derived. The experimental groups for Discriminant Analyses 5 to 8 inclusive were also males and females, but the discriminant variables employed were the NFactors from the second half of the study, that is, from Questionnaire 'C', Road-run 2 and Test-track 2. It can be seen from Table 7 that the ability to discriminate between males and females on the basis of the NFactors from the second half of the experiment was slightly reduced in comparison with the previous analyses based on NFactors from the first half of the experiment, in

... discriminant analyses performed on the NFactors derived from Factor Analyses A to F, showing the discriminant variables, experimental groups, significance of discriminant functions and the percentage of cases correctly classified.

Analysis Number	Discriminant Variables	Experimental Groups	Significance of Discriminant Functions	Cases Correctly Classified
1	NFactors 1A - 19A (Questionnaire 'B')	Males, Females	$p = .003$	74%
2	NFactors 1B - 16B (Road-run 1)	"	$p = .013$	75%
3	NFactors 1C - 7C (Test-track 1)	"	$p < .001$	77%
4	NFactors 1A - 7C (Questionnaire 'B', Road-run 1 & Test-track 1)	" "	$p < .001$	91%
5	NFactors 1D - 17D (Questionnaire 'C')	"	$p = .553$	69%
6	NFactors 1E - 15E (Road Run 2)	"	$p = .056$	69%
7	NFactors 1F - 7F (Test-track 2)	"	$p < .001$	75%
8	NFactors 1D - 7F (Questionnaire 'C', Road-run 2, Test-track 2)	"	$p < .001$	83%

TABLE 7, contd.

Analysis Number	Discriminant Variables	Experimental Groups	Significance of Discriminant Functions	Cases Correctly Classified
9	NFactors 1D - 17D (Questionnaire 'C')	Power steering groups 1 - 5 (males and females)	$p = .423$ $p = .706$ $p = .804$	48%
10	NFactors 1E - 15E (Road-run 2)	"	$p = .084$ $p = .483$ $p = .726$	47%
11	NFactors 1F - 7F (Test-track 2)	"	$p = .394$ $p = .660$ $p = .690$	38%
12	NFactors 1D - 7F (Questionnaire 'C' Road-run 2, Test-track 2)	"	$p < .001$ $p = .010$ $p = .124$	66%
13	NFactors 1D - 17D (Questionnaire 'C')	Power steering groups 1 - 5 males. Power steering groups 1 - 5 females	$p = .334$ $p = .768$ $p = .907$	50%
14	NFactors 1E - 15E (Road-run 2)	"	$p = .104$ $p = .821$ $p = .928$	48%

TABLE 7, contd.

Analysis Number	Discriminant Variables	Experimental Groups	Significance of Discriminant Functions	Cases Correctly Classified
15	NFactors 1F - 7F (Test-track 2)	Power steering groups 1 - 5 males. Power steering groups 1 - 5 females	$p = .003$ $p = .222$ $p = .441$	33%
16	NFactors 1D - 7F (Questionnaire 'C', Road-run 2, Test-track 2)	"	$p < .001$ $p = .001$ $p = .087$	63%

NOTE: Discriminant Analyses 1 - 4 were carried out on NFactors derived from data recorded in the first half of the experiment, that is, when all subjects drove with the standard power steering. Discriminant Analyses 5 - 16 were carried out on data from the second half of the experiment when subjects had been allocated to their respective power steering groups.

that fewer significant functions were derived, and the percentage of cases correctly classified was lower than that seen previously. This was to have been expected, however, since subjects were allocated to their respective power steering groups in the second half of the experiment so that an additional source of variance was present in the data from which these NFactors were derived.

The experimental groups for Discriminant Analyses 9 - 12 inclusive were the five power steering groups, namely, the Load Spring Heavy group, Load Spring Light group, Speed Proportional Feel group, Conventional Reaction group and the Control group. Each of these experimental groups contained both male and female subjects. Table 7 shows the probabilities associated with the first three discriminant functions derived in Discriminant Analyses 9 to 12, and it can be seen that only in the case of Discriminant Analysis 12, in which all the NFactors from the second half of the study were included, did any of the functions reach statistical significance. On the basis of the functions derived in Discriminant Analysis 12, 66% of cases were correctly classified. (One would expect only 20% to be correctly classified on the basis of chance alone).

When the five power steering groups were further divided into males and females to provide 10 experimental groups for the last four analyses, the most successful discrimination was again made on the basis of all the NFactors from the second half of the experiment,(Discriminant Analysis 16). The significance of the first three functions derived in each analysis is shown in Table 7, where it can be seen that the first two functions derived in Discriminant Analysis 16 were significant at the 1% level. The percentage of cases correctly classified was also much higher than would be expected by chance, since 63% were correctly classified on the basis of the functions derived, when only 10% would be expected to be correctly classified on the basis of chance alone.

In the following sections, each of the discriminant analyses is described in turn, and, for those analyses in which there were more than two experimental groups, a plot of the significant discriminant functions is given with the position of each group centroid, or mean, clearly shown. For each significant discriminant function, a list of discriminant variables with their standardized weighting coefficients is given, together with the eigenvalue, percent of trace, canonical correlation, Wilk's Lambda and the value and significance of its associated Chi-square statistic. Finally, the percentage of cases correctly classified on the basis of all functions derived is indicated either in the text or in table form.

4.4.9 DISCRIMINANT ANALYSIS 1. DISCRIMINANT VARIABLES WERE NFACTORS 1A - 19A FROM QUESTIONNAIRE 'B' (STANDARD POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE MALES AND FEMALES.

The means and standard deviations of groups' scores on NFactors 1A to 19A are given in Table 1 of Appendix N, where it can be seen that, in general, the differences between group means on each variable were relatively small and the variability in scores was relatively high. The univariate F ratios computed for each variable indicated that the differences between groups' scores on NFactors 6, 7 and 14 were significant at the 5% level. The binomial probability of three such significant results from a series of nineteen F tests is approximately .05, suggesting that this was not a purely chance result.

Since there were only two experimental groups in the first analysis, only one discriminant function was derived. A list of the highest loading discriminant variables associated with that function, their standardized weighting coefficients and the values of the group centroids on that function are given in Table 8.

From Table 9 it can be seen that the canonical correlation for the function was .56, which indicates that approximately 31% of the variance in discriminant scores is accounted for by the 'groups' variable. The value of Wilk's Lambda and associated Chi-square statistic indicate that the function was significant at the one percent level, p = .003. It was possible to correctly classify 76% of males and 72% of females on the basis of the single discriminant function.

TABLE 8. Discriminant variables (NFactors from Questionnaire 'B') standardized weighting coefficients and group centroids associated with the single function derived in Discriminant Analysis 1.

Variable	Variable Name	Standardized Weight
NFactor 3A	Willingness to manoeuvre in traffic	.62
NFactor 7A	Sensitivity, responsiveness, good feel	- .56
NFactor 6A	Favourable reaction to lightness of steering, having less to do	.44
NFactor 14A	Returning to lane earlier, lack of play	.42
NFactor 19A	Passing closer to parked vehicles, play in steering	- .41
NFactor 9A	Heavier steering and more confidence at low speeds, difficult to judge effort on sharp turns	- .36
NFactor 1A	Difficult to position car and to judge effort required, lack of confidence	.35
Group Centroids:	Group 1 (Males)	.68
	Group 2 (Females)	- .68

TABLE 9. Eigenvalue, percent of trace, canonical correlation, Wilk's Lambda and Chi-square statistic for the single function derived in Discriminant Analysis 1.

Eigen-value	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-square	D.F.	Significance
.47	100	.56	.68	34.7	15	$p = .003$

The group centroids given in Table 8 indicate that male subjects (Group 1) were associated with high positive scores, and females (Group 2), with high negative scores. This suggests that males were willing to manoeuvre the car in traffic, reacted favourably to the lightness of the steering, returned to their lane earlier having passed stationary vehicles, commented on the lack of play in the steering, but found the car difficult to position and lacked confidence in the steering. Males did not find the steering particularly sensitive, responsive or with good 'feel', did not pass closer to parked vehicles or find the steering heavier at low speeds, and did not find it difficult to judge the effort required on sharp turns. Females' high negative scores imply that they were unwilling to manoeuvre the car in traffic, found the steering sensitive, responsive and with good 'feel', did not react favourably to the lightness of the steering, returned to their lane later having passed a parked vehicle, passed closer to parked vehicles, thought the steering was heavier and were more confident at low speeds, found it easy to judge the effort required and expressed confidence in the steering.

The most interesting feature of Discriminant Analysis 1 is that, whereas males are associated with a willingness to manoeuvre the car in traffic despite finding the car difficult to position, females were apparently unwilling to manoeuvre the car in traffic although they found the steering sensitive, responsive and with good 'feel'. It would seem, therefore, that the single most important variable in discriminating between males and females on the basis of the NFactors derived from Questionnaire 'B', that is, the willingness to manoeuvre the car in traffic, was related to a favourable reaction to the lightness of the steering, but also to a certain amount of difficulty in positioning the car and judging the amount of effort required. It should be remembered, however, that the difference in males' and females' mean scores on NFactor 3A, "willingness to manoeuvre in traffic" was not significant, and that it is the linear combination of scores on all the variables associated with the function which enables a discrimination to be made between groups.

4.4.10 DISCRIMINANT ANALYSIS 2. DISCRIMINANT VARIABLES WERE NFACTORS 1B - 16B FROM ROAD-RUN 1 (STANDARD POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE MALES AND FEMALES.

The means and standard deviations of groups' scores on NFactors 1B to 16B are given in Table 2 of Appendix N, where it can be seen that, in general, the differences between group means on each variable were relatively small and there was a moderate amount of variability in scores within groups. Mean scores on NFactor 1B, "Fine steering reversals", were more extreme however, and a high degree of variability on this variable was seen for both groups. The univariate F ratios computed for each variable indicate that the differences between groups' scores on NFactors 3B, 4B and 13B were significant at the 5% level. The binomial probability of three such significant results from a total of sixteen F tests is approximately .04, suggesting that this was not a purely chance result.

A list of the highest loading discriminant variables associated with the single function derived in the second analysis, their standarized weighting coefficients and the values of the group centroids on the function, are given in Table 10.

TABLE 10. Discriminant variables (NFactors from Road-run 1) standardized weighting coefficients and group centroids associated with the single function derived in Discriminant Analysis 2.

Variable	Variable Name	Standardized Weight
NFactor 3B	Coarse steer, time, M1 and Test Area to Ampthill	.78
NFactor 4B	Coarse steer, fine steer, Kempston Town	.58
NFactor 10B	Time, coarse steer, fine steer, Ampthill to Flitwick	- .53
NFactor 8B	Time, coarse steer, fine steer, Bedford Ampthill Road	- .44
NFactor 16B	Time, coarse steer, fine steer, Bedford	- .40
NFactor 1B	Fine steering wheel reversals	.28
Group Centroids:	Group 1 (Males) - .60	
	Group 2 (Females) .60	

From Table 11 it can be seen that the canonical correlation for the function was .52, which indicates that approximately 27% of the variance in discriminant scores is accounted for by the 'groups' variable. The value of Wilk's Lambda and associated Chi-square statistic indicate that the function was significant at the two percent level, p = .013. It was possible to correctly classify 74% of males and 76% of females on the basis of the single discriminant function.

Table 11. Eigenvalue, percent of trace, canonical correlation, Wilk's Lambda and Chi-square statistic for the single function derived in Discriminant Analysis 2.

Eigen-value	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-square	D.F.	Significance
.36	100	.52	.73	28.2	14	p = .013

The values of the group centroids shown in Table 10 indicate that males were associated with high negative scores on the function and that females were associated with high positive scores. Thus, males were associated with making fewer coarse steering wheel reversals and driving more quickly over 'fast' sections of the route (M1 and trunk roads), with making fewer steering reversals in Kempston (an urban, 48 k/h, section of the route), driving more slowly and making more reversals from Ampthill to Flitwick and in Bedford Ampthill Road (both 48 k/h suburban sections of the route), with driving more slowly and making more reversals in Bedford itself (urban 48 k/h), and with making fewer fine steering reversals. Females' high positive scores were associated with making many coarse steering reversals and driving more slowly on the 'fast' sections of the route, making more steering reversals in Kempston (urban 48 k/h), driving more quickly and making fewer steering reversals from Ampthill to Flitwick and in Bedford Ampthill Road (both suburban, 48 k/h, sections of the route), driving more quickly and making fewer steering reversals in Bedford itself (urban 48 k/h), and making more fine steering reversals.

It is interesting to note that, although female subjects tended to drive more slowly and made more steering wheel reversals on fast straight roads, they drove faster and made fewer steering reversals on urban and suburban sections of the route than did the male subjects.

The relationship between speed and the number of steering reversals made is the same for both males and females, slower speeds being associated with greater numbers of both coarse and fine steering reversals. Although females tended to make a greater number of fine steering reversals overall than males, it should be remembered that there was a very high degree of variability in subjects' scores on this variable (NFactor 1B), and that its univariate F ratio was non-significant.

4.4.11. DISCRIMINANT ANALYSIS 3. DISCRIMINANT VARIABLES WERE NFACTORS 1C - 7C FROM TEST-TRACK 1 (STANDARD POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE MALES AND FEMALES.

The means and standard deviations of groups' scores on NFactors 1C to 7C are given in Table 3 of Appendix N, where it can be seen that the differences between groups' mean scores on these variables were relatively small and the variability in scores was relatively high. Mean scores on NFactors 2C, 6C and 7C were, however, more extreme, and the univariate F ratios for these variables were significant at the 5% level. The binomial probability of three such significant results from a total of seven F tests is approximately .004, indicating that this was not a purely chance result.

A list of the highest loading discriminant variables associated with the single function derived in the third analysis, their standardized weighting coefficients and the values of the group centroids on the function are given in Table 12.

From Table 13, it can be seen that the canonical correlation for this function was .53, which indicates that approximately 28% of the variance in discriminant scores is accounted for by the 'groups' variable. The value of Wilk's Lambda and associated Chi-square statistic indicate that the function was significant at the .1% level. It was possible to correctly classify 86% of males and 68% of females on the basis of the single discriminant function derived.

The values of the group centroids shown in Table 12 indicate that males were associated with high positive scores on the function and that females were associated with high negative scores. Thus, females were associated with driving more slowly on all trials, hitting more cones, (that is, driving less accurately), and to a lesser extent, making fewer steering reversals and subsidiary task responses. Males, on the other hand, were associated with driving faster and more accurately than females, making more steering reversals and making more subsidiary task responses. The univariate F ratios for the steering reversals and subsidiary task variables indicate that males' and females' scores on these variables were not significantly different.

TABLE 12. Discriminant variables (NFactors from Test-track 1), standardized weighting coefficients and group centroids associated with the single function derived in Discriminant Analysis 3.

Variable	Variable Name	Standardized Weight
NFactor 2C	Time, all trials	- .84
NFactor 7C	Cones, trial 7	- .71
NFactor 6C	Cones, trial 8	- .46
NFactor 4C	Coarse steer, fine steer, subsidiary task, trial 2	.16
NFactor 1C	Fine steer, all trials	.15
NFactor 3C	Subsidiary task, all trials	.13
NFactor 5C	Coarse steer, trials 7, 6, 4, 2 (clockwise)	.08
Group Centroids:	Group 1 (Males)	.61
	Group 2 (Females)	- .61

TABLE 13. Eigenvalue, percent of trace, canonical correlation, Wilk's Lambda and Chi-square statistic for the single function derived in Discriminant Analysis 3.

Eigen-value	Canonical Correlation	Percent of Trace	Wilk's Lambda	Chi-Square	D.F.	Significance
.38	.53	100	.72	30.5	7	$p < .001$

It is interesting to compare the percentage of cases correctly classified for males and females, which were 86% and 68% respectively. This reflects the greater variability present in females' scores and indicates that many females drove in a similar way to males on the test-track.

4.4.12 DISCRIMINANT ANALYSIS 4. DISCRIMINANT VARIABLES WERE NFACTORS 1A - 19A, 1B - 16B, 1C - 7C FROM QUESTIONNAIRE 'B', ROAD-RUN 1 AND TEST-TRACK 1 RESPECTIVELY (STANDARD POWER STEERING IN USE). EXPERIMENTAL GROUPS MALES AND FEMALES.

The means and standard deviations of groups' scores on NFactors 1A to 19A, 1B to 16B, and 1C to 7C have already been given in Appendix N, Tables 1, 2 and 3 respectively. The univariate F ratios computed for these variables indicate that groups' mean scores on NFactors 6A, 7A, 14A, 3B, 4B, 13B, 2C, 6C and 7C were significantly different at the 5% level. The probability of nine such significant results from a total of forty two F tests is less than .001*, indicating that this was not a purely chance result.

A list of the highest loading discriminant variables associated with the single function derived in Discriminant Analysis 4, their standardized weighting coefficients, and the values of the group centroids on the function are given in Table 14.

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*Since the number of F tests computed was relatively large, the normal approximation to the binomial was used in calculating this probability. The formula used was the following:

$$z = \frac{x - Np}{\sqrt{Npq}} \qquad \text{(Hays 1973, p305)}$$

where x is the number of significant F tests
N is the total number of F tests carried out
p is the 'significance level' of the F tests or α
and $q = 1 - p$

The obtained value of z is then referred to the normal distribution of standardized scores.

From Table 15, it can be seen that the canonical correlation for this function was .78, which indicates that approximately 61% of the variance in discriminant scores is accounted for by the 'groups' variable. The value of Wilk's Lambda and associated Chi-square statistic indicate that the function was significant at the .1% level. It was possible to correctly classify 92% of males and 90% of females on the basis of the single discriminant function derived.

The group centroids shown in Table 14 indicate that males were associated with high positive scores on the function, and that females were associated with high negative scores. This suggests that males were willing to manoeuvre the car in traffic, made fewer coarse steering reversals and drove faster on the motorway and trunk roads, made more reversals and drove more slowly in Bedford (urban 48 k/h), found it difficult to position the car and to judge the effort required, found the steering lighter and had less confidence at low speeds, drove faster and hit fewer cones on the test-track, and felt that the steering lacked sensitivity, responsiveness and 'feel'.

TABLE 14. Discriminant variables (NFactors from Questionnaire 'B' Road-Run 1 and Test-Track 1), standardized weighting coefficients and group centroids associated with the single function derived in Discriminant Analysis 4.

Variable	Variable Name	Standardized Weight
NFactor 3A	Willingness to manoeuvre in traffic	.88
NFactor 3B	Coarse steer and time M1 and Test Area to Ampthill	- .57
NFactor 9A	Heavier steering and more confidence at low speeds, difficult to judge effort in sharp turns	- .52
NFactor 1A	Difficult to position car and to judge effort required, lack of confidence	.48
NFactor 2C	Time, all trials	- .47
NFactor 7C	Cones, trial 7	- .46
NFactor 14A	Returning to lane earlier, lack of play	.45
NFactor 13B	Time, coarse steer, fine steer M1 to Marston	- .38
NFactor 7A	Sensitivity, responsiveness, good 'feel'	- .38
NFactor 13A	Willingness to enter small gaps on M1 and in town, difficult to keep on course over uneven roads	- .36
NFactor 4B	Coarse steer, fine steer, Kempston Town	- .35
NFactor 16B	Time coarse steer, fine steer, Bedford Town	.35
Group Centroids:	Group 1 (Males)	1.24
	Group 2 (Females)	- 1.24

TABLE 15. Eigenvalue, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistic for the single function derived in Discriminant Analysis 4.

Eigen-value	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-Square	D.F.	Significance
1.58	100	.78	.39	74.9	38	$p < .001$

Females' high negative scores imply that they were unwilling to manoeuvre the car in traffic, made more coarse steering reversals and drove more slowly on the motorway and trunk roads, made fewer reversals and drove more quickly in Bedford (urban 48 k/h), found it easy to position the car and to judge the effort required, found the steering heavier and were more confident at low speeds, drove more slowly and hit more cones on the test-track, and felt that the steering was sensitive, responsive and had good 'feel'.

The above suggests that males and females did respond differently, verbally and behaviourally, to the standard power assisted steering. Although males appeared to find it difficult to position the car and to judge the effort required, and lacked confidence in the steering, they expressed a willingness to manoeuvre the car in traffic, drove faster and more accurately on the test area, and drove faster, making fewer steering reversals, on the motorway and trunk roads. Females, on the other hand, were associated with finding the steering responsive, sensitive and with good 'feel' when manoeuvring, finding it easy to position the car, but expressing an unwillingness to manoeuvre in traffic, driving more slowly and less accurately on the test-track, and driving more slowly, making more steering reversals on the motorway and trunk roads. It should be remembered, however, that males' and females' scores on the individual NFactors included in Discriminant Analysis 4 were not significantly different in all cases. That is to say, it is the linear combination of these scores which permit a discrimination to be made between males and females rather than the groups' mean scores on individual variables.

The remaining twelve discriminant analyses were carried out on the NFactors derived from data gathered during the second half of the experiment, that is, Questionnaire 'C', Road-run 2 and Test-track 2. In the following four analyses the experimental groups were again males and females. In Discriminant Analyses 9 to 12, the experimental groups were the five power steering groups, and in the final four analyses, the five power steering groups were further divided into males and females to provide ten experimental groups. It is important to remember that in each of the following discriminant analyses subjects had been allocated to their respective power steering groups, and were, therefore, driving with an experimental power steering system, or, in the case of the control group, with the standard power steering system again.

4.4.13 DISCRIMINANT ANALYSIS 5. DISCRIMINANT VARIABLES WERE NFACTORS 1D - 17D FROM QUESTIONNAIRE 'C', (EXPERIMENTAL POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE MALES AND FEMALES.

The means and standard deviations of groups' scores on NFactors 1D to 17D are given in Table 4 of Appendix N, where it can be seen that, in general, the differences between groups' mean scores on these variables were relatively small and the variability within groups was relatively large. Only one of the univariate F ratios for these variables was significant at the 5% level, that for NFactor 9D. The binomial probability of one such significant result out of seventeen individual F tests is approximately .37, indicating that this may have been a purely chance result.

Although it was possible to correctly classify 70% of males and 68% of females on the basis of the single discriminant function derived in this analysis, it can be seen from Table 16 that the function was not significant, p = .55. The canonical correlation coefficient of .39 indicates that only approximately 15% of the variance in subjects' discriminant scores is accounted for by the 'groups' variable.

TABLE 16. Eigenvalues, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistic for the single function derived in Discriminant Analysis 5.

Eigen-value	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-Square	D.F.	Significance
.18	100	.39	.85	14.6	16	p = .55

Since the function was not statistically significant, and because the amount of variance accounted for by the groups is relatively small, no attempt will be made to interpret this function.

It is interesting to note that, whilst the present function was not statistically significant, that derived in Discriminant Analysis 1, in which the discriminant variables were the NFactors from Questionnaire 'B', was significant. This suggests that males' and females' responses to the experimental steering systems, as reflected by their scores on the NFactors from Questionnaire 'C', were different, and that this accounts for the reduced ability to discriminate between males and females seen in the present analysis. Thus, the effect of the different power steering systems on subjects' responses to Questionnaire 'C' appears to have been as great, or greater than, the effect of subjects' sex. This observation is borne out by the results of subsequent analyses of the NFactors from Questionnaire 'C' reported below (Discriminant Analyses 13 and 16) in which the experimental groups are defined with respect to both power steering groups and subjects' sex.

4.4.14 DISCRIMINANT ANALYSES 6. DISCRIMINANT VARIABLES WERE NFACTORS 1E - 15E FROM ROAD-RUN 2 (EXPERIMENTAL POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE MALES AND FEMALES.

The means and standard deviations of groups' scores on NFactors 1E to 15E are given in Table 5 of Appendix N, where it can be seen that, in general, the differences between groups' mean scores were relatively small and the variability of scores within groups was relatively large. Mean scores on NFactor 1E, however, "Fine steering reversals" were more extreme, and the variability of both males' and females' scores on this variable was extremely high. The univariate F ratios for group means on NFactors 2E, 4E and 9E were significant at the 5% level. The binomial probability of three such significant results out of a total of fifteen individual F tests is approximately .03, indicating that this was not a purely chance result.

A list of the highest loading discriminant variables associated with the single function derived in Discriminant Analysis 6, their standardized weighting coefficients and the values of the group centroids on the function are given in Table 17.

From Table 18, it can be seen that the canonical correlation coefficient for the function was .45, which indicates that approximately 20% of the variance in discriminant scores is accounted for by the 'groups' variable. The value of Wilk's Lambda and associated Chi-square statistic indicate that the function was marginally significant, $p = .06$. It was possible to correctly classify 72% of males and 66% of females on the basis of the single function derived.

TABLE 17. Discriminant variables (NFactors from Road-run 1) standardized weighting coefficients and group centroids associated with the single function derived in Discriminant Analysis 6.

Variable	Variable Name	Standardized Weight
NFactor 2E	Coarse steer, especially straight roads	.99
NFactor 7E	Driving fast and making many coarse steering reversals	- .53
NFactor 3E	Time, coarse steer, fine steer, Kempston to Bedford and Bedford	- .42
NFactor 6E	Time, coarse steer, fine steer, Ampthill	- .39
NFactor 14E	Time, coarse steer, fine steer, Ampthill to Flitwick	- .37
NFactor 13E	Slow drivers, trunk roads, M1, suburban	- .24
NFactor 8E	Time, coarse steer, fine steer, Kempston roundabout	.22
NFactor 1E	Fine steer	.21
Group Centroids:	Group 1 (Males) - .50	
	Group 2 (Females) .50	

TABLE 18. Eigenvalue, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistic for the single function derived in Discriminant Analysis 6.

Eigen-value	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-Square	D.F.	Significance
.25	100	.45	.80	20.6	12	p = .06

The values of the group centroids shown in Table 17 indicate that males were associated with moderately high negative scores on the function and that females were associated with moderately high positive scores. Thus, males were characterised by making fewer coarse steering reversals and driving more slowly on the motorway and trunk roads, driving faster and making many coarse steering reversals on some sections of the route, driving more slowly and making many steering reversals in urban areas, and making fewer fine steering reversals generally. Females, on the other hand, were associated with making more coarse steering reversals and driving faster on the motorway and trunk roads, with driving more slowly and making fewer coarse steering reversals on some sections of the route, driving faster and making fewer steering reversals in urban areas, and with making more fine steering reversals generally.

A comparison of the results of Discriminant Analysis 6 and Discriminant Analysis 2, indicates that the ability to discriminate between males and females on the basis of the NFactors derived from Road-run 2 data is somewhat reduced from that possible on the basis of the NFactors derived from Road-run 1 data. Whereas in the analysis of the NFactors from Road-run 1 males were associated with driving faster than females on the motorway and on trunk roads, and at the same time making fewer coarse steering wheel reversals, in the present analysis, males were associated with driving more slowly than females on the motorway and trunk roads although still making fewer coarse steering wheel reversals. In both discriminant analyses, however, females tended to make more fine steering wheel reversals overall than did the males, although in neither analysis was the univariate F ratio for this variable (NFactor 1E) significant. The relationship between speed and steering wheel reversals (faster speeds being associated with fewer reversals) noted for both males and females in the analysis of the NFactors from Road-run 1, does not hold in the present analysis. Thus, over some sections of the route, slow driving is associated with many coarse and fine steering reversals, whilst at other times a negative relationship between speed and coarse steering wheel reversals is seen.

It appears, therefore, that different types of power steering were having an effect on the way males and females drove. The nature of these effects will be seen more clearly from the results of later analyses.

4.4.15 DISCRIMINANT ANALYSIS 7. DISCRIMINANT VARIABLES WERE NFACTORS 1F - 7F FROM TEST-TRACK 2 (EXPERIMENTAL POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE MALES AND FEMALES.

The means and standard deviations of groups' scores on NFactors 1F to 7F are given in Table 6 of Appendix N, where it can be seen that the differences between groups' mean scores on the variables were relatively small and the variability in scores, especially amongst females, was relatively high. The univariate F ratios for these variables indicate that groups' mean scores on NFactors 2F, 5F and 6F were significantly different at the 5% level. The binomial probability of three such significant results from a total of seven individual F tests is approximately .004, indicating that this was not a purely chance result.

A list of the highest loading discriminant variables associated with the single function derived in Discriminant Analysis 7, their associated standardized weighting coefficients, and the values of the group centroids on the function are given in Table 19.

From Table 20, it can be seen that the canonical correlation coefficient for the function was .56, which indicates that approximately 31% of the variance in discriminant scores is accounted for by the 'groups' variable. The value of Wilk's Lambda and associated Chi-square statistic indicate that the function was significant at the .1% level. It was possible to correctly classify 78% of males and 72% of female subjects on the basis of the single discriminant function derived.

The values of the group centroids shown in Table 19 indicate that males were associated with high positive scores and that females were associated with high negative scores on the function. Thus, males were associated with driving faster and more accurately on the test-track, with making more steering reversals on trial one, and with making more subsidiary task responses. Conversely, females were associated with driving more slowly and less accurately, making fewer steering reversals on trial one and responding less frequently to the subsidiary task. It should be remembered, however, that the differences between males' and females' scores on the steering reversals and subsidiary task variables (NFactors 1F, 3F, 4F and 7F) were non-significant.

TABLE 19. Discriminant Variables (NFactors from Road-run 1) Standardized weighting coefficients and group centroids associated with the single function derived in Discriminant Analysis 7.

Variable	Variable Name	Standardized Weight
NFactor 2F	Time, all trials	- .95
NFactor 5F	Cones, trial 3	- .66
NFactor 4F	Coarse steer, fine steer, trial 1	.51
NFactor 6F	Cones, trial 1	- .29
NFactor 3F	Subsidiary task all trials	.25
Group Centroids:	Group 1 (Males)	.67
	Group 2 (Females)	- .67

TABLE 20. Eigenvalues, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistic for the single function derived in Discriminant Analysis 7.

Eigen-value	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-square	D.F.	Significance
.46	100	.56	.69	35.6	7	$p < .001$

A comparison of Tables 19 and 12 indicates that the results of the present analysis and that performed on the NFactors from Test-track 1 are almost identical. The close correspondence between the results of these two analyses suggests that the sex of the subject has a more powerful effect on test-track performance than the type of power steering in use. The results of the discriminant analyses performed on Test-track 1 and Test-track 2 data contrast with the results of the analyses performed on the NFactors from Questionnaires 'B' and 'C' which indicated that the effects of the different power steering systems tended to obscure the effects of sex on subjects' questionnaire responses. The relative importance of the subjects' sex and the type of power steering in use is made clearer by the results of subsequent discriminant analyses.

4.4.16 DISCRIMINANT ANALYSIS 8. DISCRIMINANT VARIABLES WERE NFACTORS 1D - 7F FROM QUESTIONNAIRE 'C', ROAD-RUN 2 AND TEST-TRACK 2 (EXPERIMENTAL POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE MALES AND FEMALES.

The means and standard deviations of groups' scores on NFactors 1D to 17D, 1E to 15E and 1F to 7F have already been given in Appendix N, Tables 4, 5 and 6 respectively. Univariate F tests indicate that groups' mean scores on NFactors 9D, 2E, 4E, 9E, 2F, 5F and 6F were significantly different at the 5% level. The probability of seven such significant results from a total of thirty nine individual F tests is less than .001, indicating that this was not a purely chance result. (The normal approximation to the binomial was used to calculate this probability.)

A list of the highest loading discriminant variables associated with the single function derived in Discriminant Analysis 6, their standardized weighting coefficients and the values of the group centroids on the function are given in Table 21.

From Table 22 it can be seen that the canonical correlation coefficient for the function was .67, which indicates that approximately 45% of the variance in discriminant scores is accounted for by the 'groups' variable. The value of Wilk's Lambda and associated Chi-square statistic indicate that the function was significant at the .1% level. It was possible to correctly classify 84% of males and 82% of female subjects on the basis of the single function derived.

TABLE 21. Discriminant Variables (NFactors from Questionnaire 'C', Road-run 2 and Test-track 2), standardized weighting coefficients and group centroids associated with the single function derived in Discriminant Analysis 8.

Variable	Variable Name	Standardized Weight
NFactor 2F	Time, all trials	- .81
NFactor 4F	Coarse steer, fine steer, trial 1	.64
NFactor 5F	Cones, trial 3	- .55
NFactor 15D	More effort when cornering hard, feeling more frustrated	- .42
NFactor 9D	Holding back less, lack of 'feel', more confidence at high speeds than low speeds	- .41
NFactor 10D	Sensitivity, responsiveness, easy to position	- .38
NFactor 2E	Coarse steer, straight roads	- .36
NFactor 17D	Forcefulness of return to straight ahead, confidence at low speeds, steering too light at higher speeds	- .31
NFactor 9E	Time, coarse steer, fine steer, Bedford to Test Area	- .26
NFactor 1D	Difficult to judge effort required, tendency to oversteer, difficult to get used to	- .26
NFactor 3F	Subsidiary task all trials	.20

Group Centroids:	Group 1 (Males)	.90
	Group 2 (Females)	- .90

TABLE 22. Eigenvalue, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistic for the single function derived in Discriminant Analysis 8.

Eigen-value	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-square	D.F.	Significance
.83	100	.67	.55	55.6	12	$p < .001$

The values of the group centroids given in Table 21 indicate that males were associated with high positive scores on the function and that females were associated with high negative scores. Although all the NFactors derived from the data from the second half of the experiment were included in the present analysis, it can be seen from Table 21 that those NFactors derived from Test-track 2 data were the most important in discriminating between the experimental groups. This was to have been expected, however, since Discriminant Analysis 7, performed on the NFactors from Test-track 2, provided the most effective discriminant function of any of the preceeding three analyses of NFactors from the second half of the experiment. Thus, males were associated with driving faster and more accurately on the test-track, with making more steering reversals on trial one, and with responding more frequently to the subsidiary task. Females were associated with driving more slowly and less accurately on the test-track, with making fewer reversals on the first trial and with responding less frequently to the subsidiary task.

In terms of the NFactors from Questionnaire 'C' and Road-run 2, males were associated with there being less effort required when cornering hard, holding back more, feeling that the steering lacked sensitivity, responsiveness and was difficult to position, making fewer coarse steering reversals on straight roads, finding the steering returned less forcefully to the straight ahead position, driving faster and making fewer steering reversals on the last section of the route and finding it difficult to judge the effort required to steer the car. Females, on the other hand, were associated with there being more effort required when cornering hard, holding back less, finding that the steering was sensitive, responsive and easy to position, making more coarse steering reversals on straight roads, finding that the steering returned more forcefully to the straight ahead position, driving more slowly and making more steering reversals on the last section of the route and finding it difficult to judge the effort required to steer the car. Again it must be remembered that groups' mean scores on individual NFactors were, in many cases, not significantly different, and it is the linear combination of scores which enables groups to be discriminated rather than group means on individual variables.

Although the inclusion of the NFactors from Questionnaire 'C' and Road-run 2 in the present analysis enabled more effective discrimination to be made between the experimental groups than that provided in the previous analysis of Test-track 2 data alone, in that a greater percentage of subjects were correctly classified, it is difficult to interpret the contribution made by these variables. As noted previously, the differences in subjects' responses to the various experimental power steering systems in terms of the Questionnaire items and their driving on Road-run 2 seem to have been greater than those due to subjects' sex. It will be seen from the results of the following analyses that males and females did indeed react differently to the experimental power steering systems.

The following four discriminant analyses, reported below, were also carried out on the NFactors derived from Questionnaire 'C', Road-run 2 and Test-track 2 data. The experimental groups definedfor Discriminant Analyses 9 to 12 inclusive are referred to as power steering groups 1 to 5. Power steering group one contains the ten male and ten female subjects assigned to the Fitted Load Spring Heavy system. Power steering group two contains the ten male and ten female subjects assigned to the Fitted Load Spring Light System. Power steering group three contains the ten male and ten female subjects assigned to the Speed Proportional Feel system. Power steering group four contains the ten male and ten female subjects assigned to the Conventional Reaction system. Finally, power steering group five contains the ten male and ten female subjects who drove with the standard power steering system in both halves of the experiment and who formed the Control group.

The inclusion of five experimental groups in Discriminant Analyses 9 to 12 means that a maximum of four discriminant functions can be derived.

4.4.17 DISCRIMINANT ANALYSIS 9. DISCRIMINANT VARIABLES WERE NFACTORS 1D - 17D FROM QUESTIONNAIRE 'C' (EXPERIMENTAL POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE POWER STEERING GROUPS 1 - 5.

The means and standard deviations of groups' scores on NFactors 1D to 17D are given in Table 7 of Appendix N, where it can be seen that the differences between groups' mean scores were relatively small, and the variability in scores was relatively large, and roughly comparable, for each group. The univariate F ratios indicate that only groups' mean scores on NFactor 5D were significantly different, $p < .05$. The binomial probability of one such significant F ratio from a total of seventeen tests is approximately .37, indicating that this is likely to have been a purely chance result.

Although it was possible to correctly classify 48% of subjects on the basis of the four functions derived in Discriminant Analysis 9, it can be seen from Table 23 that none of the functions reached statistical significance. The canonical correlation associated with the first, and therefore most important, discriminant function was .52, which indicates that approximately 27% of the variance in discriminant scores is accounted for by the 'groups' variable. Reference to Table 16 shows that for the single function derived in Discriminant Analysis 5, which sought to discriminate between males and females on the basis of the Questionnaire 'C' NFactors, approximately 15% of the variance in discriminant scores was accounted for by the experimental groups. Considered together, therefore, the results of Discriminant Analyses 5 and 9 suggest that a relatively small proportion of variance in subjects' scores on Questionnaire 'C' is accounted for by the subject's sex or the power steering group to which he was assigned, although more variance is accounted for by the power steering system than by the subject's sex. This finding is supported by a later analysis in which the experimental groups were defined in such a way as to represent both sex and the power steering system to which the subject was allocated.

TABLE 23. Eigenvalue, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistics for the four functions derived in Discriminant Analysis 9.

Function	Canonical Correlation	Eigenvalue	Percent of Trace	Wilk's Lambda	Chi-square	Degrees of Freedom	Significance
1	.52	.37	41	.45	69.8	68	p = .42
2	.44	.24	27	.62	42.3	48	p = .71
3	.38	.17	19	.77	23.3	30	p = .80
4	.32	.11	3	.90	9.4	14	p = .80

Since none of the functions derived in Discriminant Analysis 9 were statistically significant, no attempt will be made to interpret the results of this analysis.

4.4.18 DISCRIMINANT ANALYSIS 10. DISCRIMINANT VARIABLES WERE NFACTORS 1E - 15E FROM ROAD-RUN 2 (EXPERIMENTAL POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE POWER STEERING GROUPS 1 - 5.

The means and standard deviations of groups' scores on NFactors 1E to 15E are given in Table 8 of Appendix N, where it can be seen that the differences between groups' mean scores were relatively small, and the variability in scores was relatively large, and roughly comparable, for each group. The univariate F ratios indicate that groups' mean scores on NFactors 2E and 9E were significantly different at the 5% level. The binomial probability of two such significant results from a total of fifteen F tests is approximately .12, indicating that this may have been a chance result. Pair-wise comparisons* of NFactor 2E means suggest that the Control group's mean score was significantly different from those of the Load Spring Heavy, Load Spring Light and Conventional Reaction group. Pair-wise comparisons of NFactor 9E means produced the same pattern of differences with the addition of a significant difference between the Load Spring Heavy and Speed Proportional Feel group's mean scores.

Of the four discriminant functions derived in this analysis, it can be seen from Table 24 that only the first approached significance, p = .08. A list of the highest loading discriminant variables associated with this function, their

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*The SPSS output from subprogram 'Discriminant' does not include the MS error term associated with univariate F ratios, so that it was not possible to make multiple comparisons in the normal way. The simple expedient of a t test for the difference between two means was used, therefore, that is:

$$t = \frac{(M1 - M2) - E(M1 - M2)}{\text{est}\,\sigma_{\text{diff}}} \qquad \text{(See Hays, 1973, p.409)}$$

Two-tailed tests of significance were used.

standardized weighting coefficients and the values of the group centroids on the function are given in Table 25.

TABLE 24. Eigenvalues, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistics for the four functions derived in Discriminant Analysis 10.

Function	Eigenvalue	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-square	Degrees of Freedom	Significance
1	.46	47	.56	.43	75.7	60	p = .084
2	.26	26	.45	.63	41.7	42	p = .483
3	.19	19	.40	.79	21.3	26	p = .726
4	.07	7	.25	.94	6.0	12	p = .917

From Table 24 it can be seen that the canonical correlation associated with the first function was .56, which indicates that approximately 31% of the variance in discriminant scores is accounted for by the 'groups' variable. It was possible to correctly classify an average of 47% of subjects over all power steering groups on the basis of the four functions derived, and the full classification matrix is shown in Table 26. A plot of the group centroids on the first discriminant function is shown in Figure 6.

From Figure 6 it can be seen that the first discriminant function best separates group five, the Control Group, from all the other experimental groups. To some extent group three, the Speed Proportional Feel group, is also separated from groups one, two and four, the Load Spring Heavy, Load Spring Light and the Conventional Reaction groups respectively. The variables associated with the Control Group are large numbers of coarse steering wheel reversals on the motorway and trunk roads, faster speeds and fewer steering wheel reversals in Ampthill, (urban 48 k/h) and from Kempston to Bedford (suburban 48 k/h), faster speeds from Flitwick to Westoning and through Westoning (rural 96 k/h and urban 48 k/h respectively), slower speeds and more steering reversals from Westoning to the M1 (trunk road), slower speeds and fewer coarse steering reversals on some sections of the route, and more fine steering wheel reversals. Variables associated with groups one, two and four are few coarse steering reversals on the motorway and trunk roads, slower speeds and more

TABLE 25. <u>Discriminant Variables (NFactors from Questionnaire 'C', Standardized Weighting Coefficients and Group Centroids associated with the first function derived in Discriminant Analysis 10</u>.

Variable	Variable Name	Standardized Weight
NFactor 2E	Coarse steer, especially straight roads	.69
NFactor 6E	Time, coarse steer, fine steer, Ampthill	- .53
NFactor 1E	Fine steer	.48
NFactor 10E	Time Flitwick to Westoning Time Westoning	- .37
NFactor 7E	Driving fast and making many coarse steering reversals	- .37
NFactor 3E	Time, coarse steer, fine steer, Kempston to Bedford and Bedford	- .35
NFactor 15E	Time, coarse steer, fine steer, Westoning to M1	.31
Group Centroids:	Group 1 Load Spring Heavy	- .29
	Group 2 Load Spring Light	- .60
	Group 3 Speed Proportional Feel	.08
	Group 4 Conventional Reaction	- .43
	Group 5 Control Group	1.25

steering wheel reversals in Ampthill (urban 48 k/h) and Kempston to Bedford (suburban 48 k/h), slower speeds from Flitwick to Westoning and through Westoning (rural 96 k/h and urban 48 k/h respectively), faster speeds and fewer steering reversals from Westoning to the M1 (trunk road), faster speeds and more steering reversals on some sections of the route, and fewer fine steering reversals.

Although this function does not discriminate equally well between all of the groups, and, it must be remembered, the function was only marginally significant, it does give us some information about group five, the Control group, in relation to the other groups, especially groups one, two and four, the Load Spring Light, Load Spring Heavy and Conventional Reaction groups respectively.

TABLE 26. Percent of cases correctly and incorrectly classified on the basis of the four functions derived in Discriminant Analysis 10.

Actual Group Membership	Predicted Group Membership				
	1	2	3	4	5
1	50%	5%	15%	10%	20%
2	15%	40%	20%	10%	15%
3	10%	15%	40%	20%	15%
4	15%	20%	15%	35%	15%
5	5%	5%	20%	0%	70%

Group 1 Load Spring Heavy
Group 2 Load Spring Light
Group 3 Speed Proportional Feel
Group 4 Conventional Reaction
Group 5 Control Group

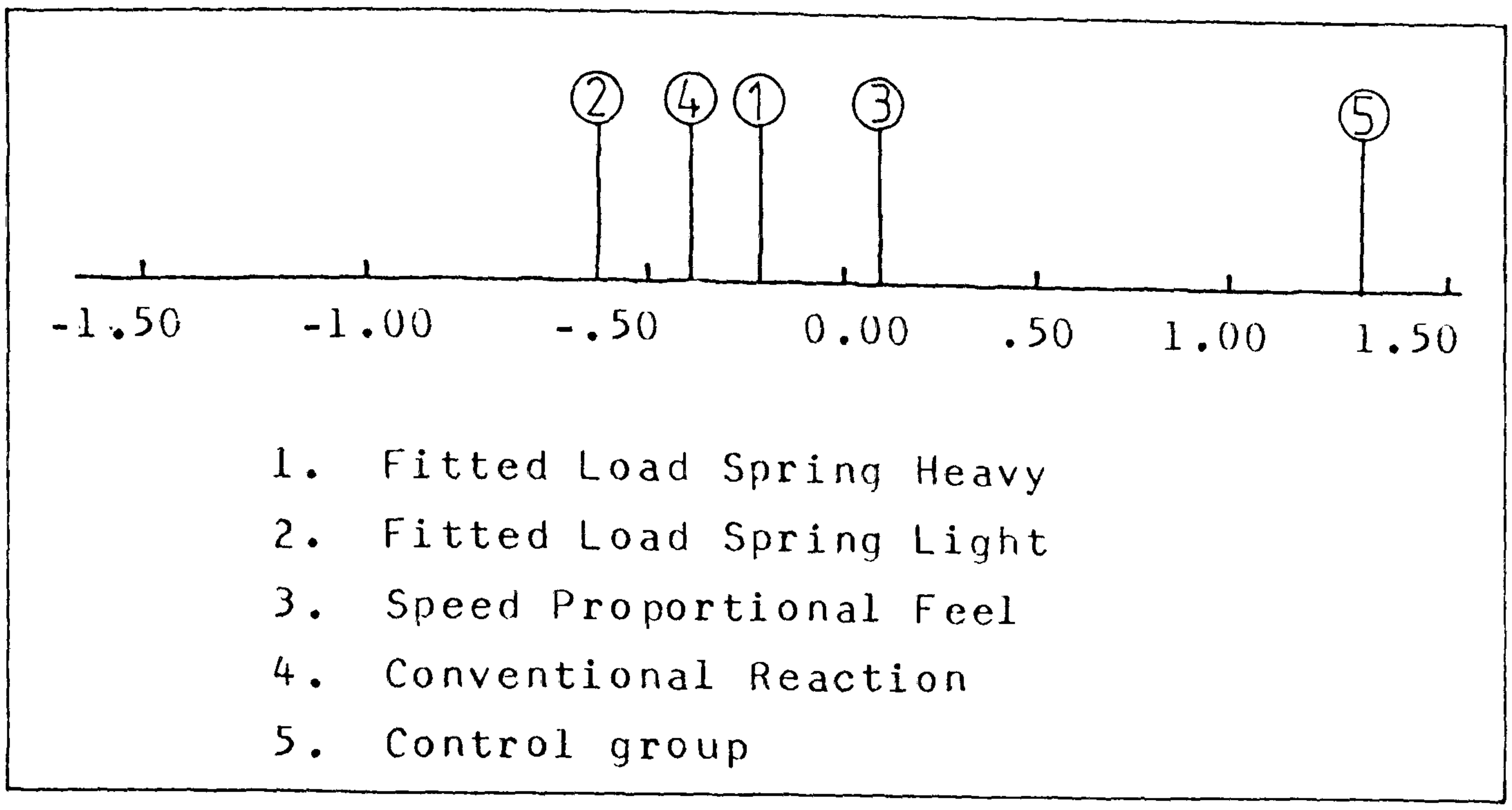


FIGURE 6. Group centroids plotted on the first discriminant function from Discriminant Analysis 10.

Thus the Control Group, whilst not driving more slowly than the other groups on the motorway or trunk roads, were associated with making more coarse steering reversals than the Load Spring Heavy, Load Spring Light, Conventional Reaction Group, and, to some extent, the Speed Proportional Feel Group. However, on some urban and suburban (48 k/h) sections, the Control Group were associated with driving faster and making fewer steering wheel reversals than these other groups. There was also a tendency for the Control Group to make more fine steering wheel reversals overall than the other groups, although, as noted previously, the univariate F ratio for this variable (NFactor 1E) was non-significant.

4.4.19 DISCRIMINANT ANALYSIS 11. DISCRIMINANT VARIABLES WERE NFACTORS 1F - 7F FROM TEST-TRACK 2 (EXPERIMENTAL POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE POWER STEERING GROUPS 1 - 5.

The means and standard deviations of groups' scores on NFactors 1F to 7F are given in Table 9 of Appendix N, where it can be seen that the differences between groups' mean scores were relatively small and the variability in scores was relatively large. The univariate F ratios indicate that groups' mean scores on the variables from Test-track 2 were not significantly different.

It was possible to correctly classify an average of 38% of subjects on the basis of the four functions derived in Discriminant Analysis 11. Reference to Table 27 indicates however, that none of these functions was statistically significant.

A comparison of the results of the present analysis and those of Discriminant Analysis 7, in which the MFactors from Test-track 2 were used to discriminate between males and females, suggest that a greater proportion of the variance in subjects' scores is accounted for by the subjects' sex than by the power steering system to which he was assigned. Thus, the canonical correlation for the first and, therefore, the most important discriminant function from this analysis was .38, which indicates that approximately 14% of the variance in discriminant scores was accounted for by the experimental

TABLE 27. <u>Eigenvalue, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistics for the four functions derived in Discriminant Analysis 11.</u>

Function	Eigenvalue	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-square	Degrees of Freedom	Significance
1	.17	50	.38	.73	29.4	28	p = .394
2	.08	26	.26	.85	15.0	18	p = .660
3	.06	18	.24	.92	7.4	10	p = .690
4	.02	6	.14	.98	1.9	4	p = .754

'groups' (power steering) variable. The canonical correlation associated with the single function derived in Discriminant Analysis 7 was .56, which indicates that 31% of the variance in discriminant scores was accounted for by the experimental groups (males and females) in that analysis.

Since none of the discriminant functions derived in Discriminant Analysis 11 were statistically significant, no attempt will be made to interpret the results of this analysis.

4.4.20 DISCRIMINANT ANALYSIS 12. DISCRIMINANT VARIABLES WERE NFACTORS 1D - 7F FROM QUESTIONNAIRE 'C', ROAD-RUN 2 AND TEST-TRACK 2 (EXPERIMENTAL POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE POWER STEERING GROUPS 1 - 5.

The means and standard deviations of groups' scores on NFactors 1D to 17D, 1E to 15E, and 1F to 7F have already been given in Appendix N, Tables 7, 8 and 9 respectively. The univariate F ratios, also reported in earlier sections, indicate that groups' mean scores on NFactors 5D, 2E and 9E were significantly different at the 5% level. The probability of three such significant results from a total of thirty nine F tests is approximately .22, indicating that this is likely to have been a chance result. (The normal approximation to the binomial was used to calculate this probability.)

Of the four discriminant functions derived in this analysis, it can be seen from Table 28 that the first two of these were significant at the 1% level. A list of the highest loading variables on these two functions, their standardized weighting coefficients, and the values of the group centroids on each function are given in Table 29.

From Table 28 it can be seen that the canonical correlation associated with the first function was .71, which indicates that 50% of the variance in discriminant scores is accounted for by the experimental 'groups' variable. The canonical

TABLE 28. Eigenvalue, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistic for the four functions derived in Discriminant Analysis 12.

Function	Eigenvalue	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-square	Degrees of Freedom	Significance
1	1.00	46	.71	.19	144.8	80	$p < .001$
2	.57	26	.60	.37	85.0	57	$p = .010$
3	.31	14	.44	.59	45.9	36	$p = .124$
4	.29	13	.48	.77	22.3	17	$p = .174$

correlation associated with the second discriminant function was .60, which indicates that approximately 36% of the variance in discriminant scores is accounted for by the experimental 'groups' variable. The percent of trace, that is, the proportion of the total variance accounted for by the two functions was 46% and 26% respectively. It was possible to correctly classify an average of 66% of subjects over all power steering groups on the basis of the four functions derived and the full classification matrix is given in Table 30. A plot of the group centroids on the two significant discriminant functions is shown in Figure 7.

It can be seen from Figure 7 that all the experimental groups are fairly well separated on discriminant function 1 except groups two and four, the Load Spring Light and Conventional Reaction groups respectively.

Thus, on the first discriminant function, the Load Spring groups and the Conventional Reaction group, that is, groups one, two and four, are associated with the steering being

TABLE 29 Discriminant Variables (NFactors from Questionnaire 'C', Road-run 2 and Test-track 2), standardized weighting coefficients and group centroids associated with the first two functions derived in Discriminant Analysis 12.

Variable	Variable Name	Standardized Weight
Function 1		
NFactor 8D	Steering too light, no different	- .77
NFactor 9E	Time, coarse steer, fine steer, Bedford to Test Area	- .76
NFactor 2E	Coarse steer, especially straight roads	- .72
NFactor 5F	Cones, trial 3	.60
NFactor 10E	Time Flitwick to Westoning, Time Westoning	.45
NFactor 14E	Time, coarse steer, fine steer, Ampthill to Flitwick	.45
NFactor 16D	Less play in steering, taking longer at mini-roundabouts	.37
Function 2		
NFactor 8D	Steering too light, no different	- .63
NFactor 5D	Driving faster, overtaking, easier to control	.54
NFactor 2D	Difficult to maintain lane position, difficult to control during lane-change, lack of confidence at speed	- .47
NFactor 8E	Time, coarse steer, fine steer Kempston roundabout	- .45
NFactor 10D	Sensitive, responsive, easy to position	.45

		Discriminant Function 1	Discriminant Function 2
Group Centroids:	Group 1 Load Spring Heavy	1.24	.35
	Group 2 Load Spring Light	.50	- .25
	Group 3 Speed Prop Feel	- .60	1.25
	Group 4 Con Reaction	.42	- .84
	Group 5 Control Group	-1.55	- .51

TABLE 30. Percent of cases correctly and incorrectly classified on the basis of the four functions derived in Discriminant Analysis 12.

Actual Group Membership	Predicted Group Membership				
	1	2	3	4	5
1	65%	20%	10%	5%	0%
2	15%	55%	5%	15%	10%
3	5%	5%	75%	10%	5%
4	10%	10%	0%	70%	10%
5	5%	5%	20%	5%	65%

Group 1 Load Spring Heavy
Group 2 Load Spring Light
Group 3 Speed Proportional Feel
Group 4 Conventional Reaction
Group 5 Control Group

too heavy and different, with driving faster and making fewer coarse steering reversals on the last section of the route, with making fewer coarse steering reversals on the M1 and trunk roads, hitting more cones on trial three of the test-track session, driving more slowly and making more steering wheel reversals on a suburban section of the route, driving more slowly on a section of rural roads and a section of urban driving, and with commenting on there being less play in the steering. The Control group and Speed Proportional Feel group, that is, groups five and three, are associated on function one with finding the steering too light and no different, with driving more slowly and making many steering wheel reversals on the last section of the route, making more coarse steering reversals on the M1 and trunk roads, hitting fewer cones on trial 3 of the test-track session, driving faster on a section of rural roads and a section of urban driving, driving faster and making fewer steering wheel reversals on a suburban section of the route, and with commenting on there being more play in the steering.

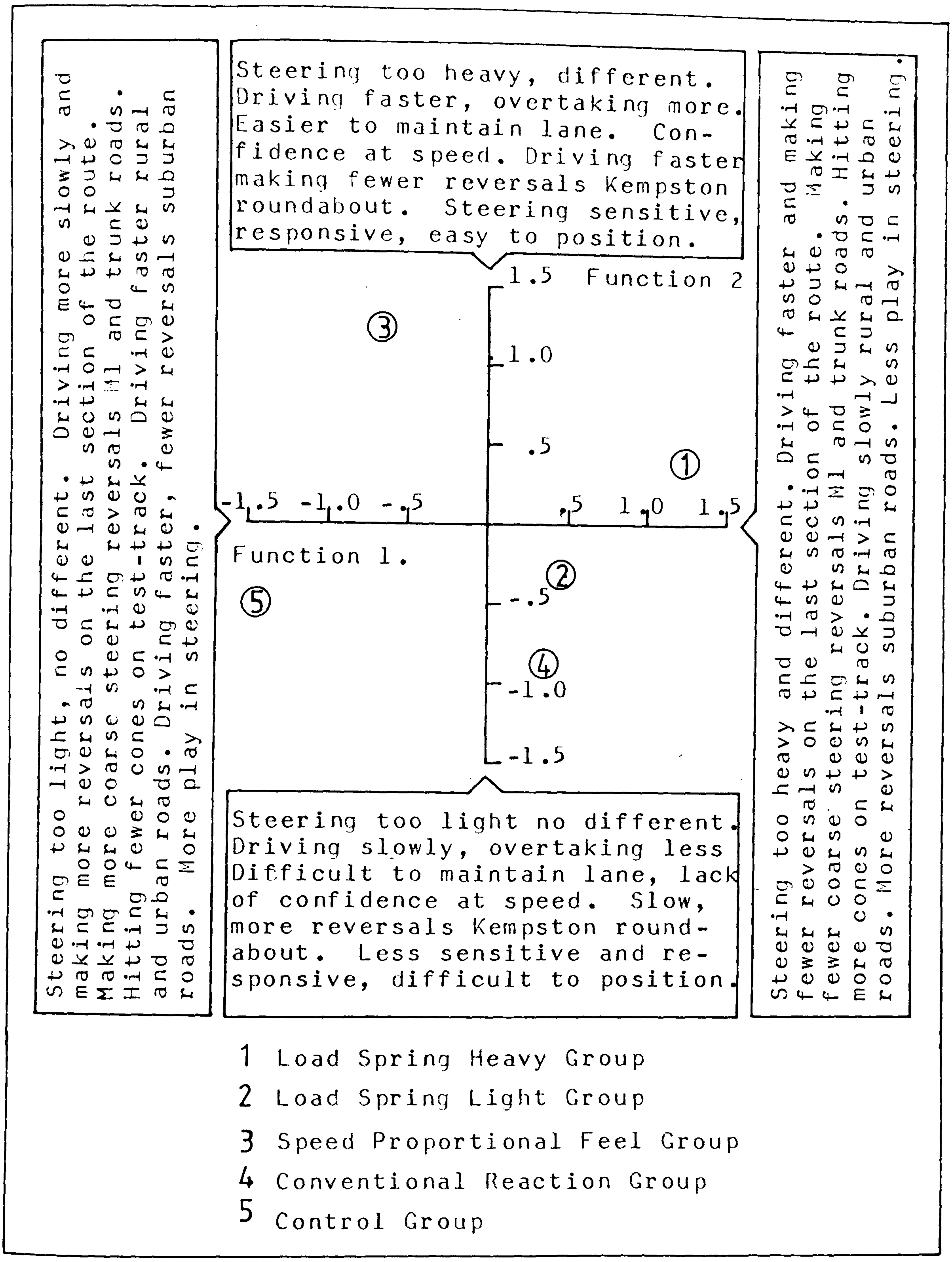


FIGURE 7. Plot of group centroids on the first two significant functions from Discriminant Analysis 12. Discriminant variables were NFactors derived from Questionnaire 'C', Road-run 2 and Test-track 2. Power steering groups 1 to 5.

It is not surprising that the Load Spring Heavy group was associated with finding the steering "too heavy" and "different", since it was indeed heavier than the standard power steering system which subjects drove with on Road-run 1. The association of the Fitted Load Spring Light group and the Conventional Reaction group with the variables "too heavy" and "different" is also understandable, in that both systems involved some increased effort at the steering wheel, the former a constantly increased effort, the latter an increase in effort proportional to system pressure.

The fact that groups five and three, the Control group and the Speed Proportional Feel group, were associated with finding the steering "too light" and "no different" is also not a surprising result since the Control group's standard power steering was in fact "no different" and, except at speed, the Proportional Feel system is very similar to standard power steering. The difference between the two systems is reflected in their relative positions on function 1, the Control group being placed closer to the "too light" and "no different" end than the Speed Proportional Feel group.

It is interesting to note that both the Fitted Load Spring groups and the Conventional Reaction group were associated with driving faster and making fewer reversals on high speed roads, but with driving more slowly and making more reversals on lower speed roads, hitting more cones on the test-track than the Speed Proportional Feel and Control groups. The Load Spring and Conventional Reaction groups felt that there was less play in the steering, the Control group and Speed Proportional Feel group felt there was more play.

Discriminant function two more effectively discriminates between the Conventional Reaction and the Fitted Load Spring Light groups whilst maintaining a good separation between all groups. It can be seen from Figure 7 and Table 29, that the Speed Proportional Feel group and, to a lesser extent, the Load Spring Heavy group are associated with the steering being too heavy and different, with driving faster and over-taking more often, finding it easy to maintain lane position on the motorway, having confidence at speed, driving more quickly and making fewer reversals over a section containing a particularly difficult roundabout, finding the steering sensitive, responsive and easy to position. The Conventional Reaction group, Control group and Fitted Load Spring Light group, were associated with the steering being too light and no different, driving more slowly and overtaking less, having difficulty maintaining lane position on the motorway, a lack of confidence at speed, taking longer and making more steering reversals at Kempston roundabout, finding the steering less sensitive and responsive and difficult to position.

It is interesting to note that NFactor 8D, "Steering too light, no different", was the highest loading discriminant variable on both function 1 and function 2 from this analysis. Although the univariate F ratio was not significant, group means on this variable reflect exactly the positions which would be predicted from a knowledge of the design characteristics of the power steering systems. Thus, the Load Spring Heavy group have the most extreme negative score on this variable, that is, "too heavy and different", with the Conventional Reaction group and Load Spring Light group having less extreme negative scores. The Speed Proportional Feel group have an almost zero mean score on NFactor 8D, and the Control group an extreme positive score, that is, "too light and no different".

Although NFactor 5D contributed to the discrimination between groups ("driving faster, overtaking more frequently, easier to control"), the absence of a 'time' factor based on objective recording suggests that there were no real differences between groups' overall speed on Road-run 2.

The final four discriminant analyses carried out on the NFactors derived from data from the second half of the experiment were based on ten experimental groups. These were the five power assisted steering system groups further split into males and females. The subjects contained in the ten experimental groups were as follows:

Group 1	Fitted Load Spring Heavy, Males
Group 2	Fitted Load Spring Heavy, Females
Group 3	Fitted Load Spring Light, Males
Group 4	Fitted Load Spring Light, Females
Group 5	Speed Proportional Feel, Males
Group 6	Speed Proportional Feel, Females
Group 7	Conventional Reaction, Males
Group 8	Conventional Reaction, Females
Group 9	Control Group, Males
Group 10	Control Group Females

Since ten experimental groups were included in each of the remaining discriminant analyses, it was possible to derive a maximum of 9 discriminant functions in each case.

4.4.21 DISCRIMINANT ANALYSIS 13. DISCRIMINANT VARIABLES WERE NFACTORS 1D - 17D FROM QUESTIONNAIRE 'C' (EXPERIMENTAL POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE POWER STEERING GROUPS 1 - 10.

The means and standard deviations of groups' scores on NFactors 1D to 17D are given in Table 10 of Appendix N, where it can be seen that the differences between groups' mean scores were relatively small and the variability in scores was relatively large. In general, female power steering groups were associated with more extreme mean scores and a higher variability than male power steering groups. The univariate F ratios computed for these variables were in all cases non-significant.

Reference to Table 31 indicates that none of the functions derived in this analysis was statistically significant, although the canonical correlation and percent of trace for the first function indicates that approximately 40% of the variance in discriminant scores on the function was accounted for by the 'groups' variable, and that 31% of the total discriminant variance was accounted for by the first function. An average of 50% of subjects were correctly classified on the basis of the nine discriminant functions derived.

TABLE 31. Eigenvalue, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistics for the nine functions derived in Discriminant Analysis 13.

Function	Eigenvalue	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-square	Degrees of Freedom	Significance
1	.67	31	.63	.15	160.0	153	p = .334
2	.42	19	.54	.26	116.1	128	p = .768
3	.33	15	.58	.36	86.0	105	p = .907
4	.23	10	.43	.49	71.7	84	p = .965
5	.16	8	.38	.60	44.2	65	p = .974
6	.14	6	.35	.69	31.2	48	p = .971
7	.12	5	.33	.79	20.0	34	p = .963
8	.07	3	.26	.89	10.2	20	p = .963
9	.05	2	.22	.95	4.2	9	p = .899

Taken together with the results of previous analyses of the NFactors from Questionnaire 'C', that is, Discriminant Analyses 5 and 9, it is clear that subjects' responses to the questionnaire alone do not provide an adequate means of distinguishing between males and females, the five power steering groups, or males and females within each power steering group.

Since the functions derived in Discriminant Analysis 13 failed to reach significance, no attempt will be made to interpret the results of this analysis.

4.4.22 DISCRIMINANT ANALYSIS 14. DISCRIMINANT VARIABLES WERE NFACTORS 1E - 15E FROM ROAD-RUN 2 (EXPERIMENTAL POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE POWER STEERING GROUPS 1 - 10.

The means and standard deviations of groups' scores on NFactors 1E to 15E are given in Table 11 of Appendix N, where it can be seen that the differences between groups' mean scores were relatively small and the variability in scores was relatively large, and roughly comparable, within each group. The univariate F ratios indicate that the differences in groups' mean scores on NFactors 2E and 9E were significant at the 1% level. The binomial probability of two such significant results from a total of fifteen F tests is approximately .01, which suggests that this was not a purely chance result.

Pair-wise comparisons of NFactor 2E means indicate that Control group females differed significantly from Conventional Reaction males, Speed Proportional Feel males, Load Spring Light males and Load Spring Heavy females. Control group males differed significantly from males in each of the other power steering groups. Females in the Speed Proportional Feel group differed significantly from males in the Load Spring Heavy group, and there was a significant difference between males and females in the Load Spring Light group. Pair-wise comparisons of NFactor 9E means indicate that Control group males differed significantly from males and females in the Load Spring Heavy and Load Spring Light groups, and from males in the Conventional Reaction group. Speed Proportional Feel females differed significantly from males and females in the Load Spring Heavy and Load Spring Light groups, and males in the Conventional Reaction and Speed Proportional Feel groups ($p < .05$ in all cases).

The trends which emerge from this rather complex set of results are that, in terms of NFactor 2E ("Coarse steer, especially straight roads") and NFactor 9E ("Time, coarse steer, fine steer Bedford to Test Area"), males tend to differ from females, males in the Control group tend to differ from males in the other power steering groups, males and females in the same power steering groups do not tend to differ, and females in different power steering groups do not tend to differ.

It can be seen from Table 32 that, of the nine discriminant functions derived in this analysis, only the first was marginally significant, $p = .104$. A list of the highest loading variables on this function, their standardized weighting coefficients and the values of the group centroids on the function are given in Table 33.

From Table 32 it can be seen that the canonical correlation associated with the first discriminant function was .70, which indicates that approximately 50% of the variance in discriminant scores is accounted for by the experimental 'groups' variable. The proportion of the total variance accounted for by the first function, indicated by the percent of trace, was 43%. It was possible to correctly classify 48% of subjects on the basis of all nine functions, and the full classification matrix is given in Table 34. A plot of the group centroids on the first function is shown in Figure 8.

TABLE 32. Eigenvalues, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistics for the nine functions derived in Discriminant Analysis 14.

Function	Eigenvalue	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-square	Degrees of Freedom	Significance
1	.95	43	.70	.16	155.9	135	$p = .10$
2	.35	16	.51	.32	98.2	112	$p = .82$
3	.24	11	.44	.44	71.9	91	$p = .93$
4	.20	9	.41	.54	53.0	72	$p = .95$
5	.16	7	.37	.65	37.0	55	$p = .97$
6	.11	5	.32	.76	24.0	40	$p = .98$
7	.09	4	.29	.84	14.8	27	$p = .97$
8	.06	3	.24	.92	7.4	16	$p = .97$
9	.03	1	.16	.97	2.4	7	$p = .94$

The most notable feature of Figure 8 is that males and females assigned to the same power steering system are not necessarily placed close together on the discriminant function. Thus, males and females in the Load Spring Heavy Group (groups one and two), and males and females in the Load Spring Light Group (groups three and four), are widely separated as are males and females in the Speed Proportional Feel group (groups five and six). Males and females form a more homogeneous group in the case of the Conventional Reaction group (groups seven and eight), and Control group (groups nine and ten), however. Generally, males, with the exception of those in the Control group, tend towards negative scores on the discriminant function whilst females, with the exception of the Conventional Reaction group, tend towards positive scores.

TABLE 33. Discriminant Variables (NFactors from Road-run 2) Standardized Weighting Coefficients and Group Centroids associated with the first function derived in Discriminant Analysis 14.

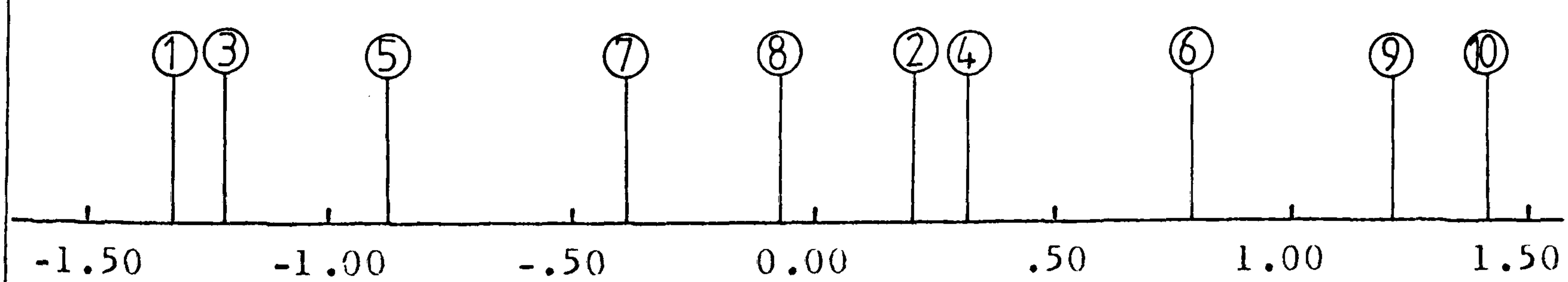
Variable	Variable Name	Standardized Weight
NFactor 2E	Coarse steer, especially straight roads	.94
NFactor 3E	Time, coarse steer, fine steer Kempston to Bedford and Bedford	- .53
NFactor 7E	Driving fast and making many coarse steering reversals	- .47
NFactor 14E	Time, coarse steer, fine steer Ampthill to Flitwick	- .47
NFactor 6E	Time, coarse steer, fine steer Ampthill	- .43
NFactor 9E	Time, coarse steer, fine steer Bedford to Test Area	.42
NFactor 1E	Fine steer	.41

Group Centroids:	Group 1 Load Spring Heavy, Males	- 1.31
	Group 2 Load Spring Heavy, Females	.27
	Group 3 Load Spring Light, Males	- 1.24
	Group 4 Load Spring Light, Females	.21
	Group 5 Speed Proportional Feel, Males	- .87
	Group 6 Speed Proportional Feel, Females	.83
	Group 7 Conventional Reaction, Males	- .42
	Group 8 Conventional Reaction, Females	- .11
	Group 9 Control Group, Males	1.23
	Group 10 Control Group, Females	1.42

TABLE 34 Percent of cases correctly and incorrectly classified on the basis of the nine functions derived in Discriminant Analysis 14.

Actual Group Membership	Predicted Group Membership									
	1	2	3	4	5	6	7	8	9	10
1	50%	20%	10%	0%	10%	0%	10%	0%	0%	0%
2	0%	70%	0%	0%	0%	10%	0%	10%	0%	10%
3	0%	30%	50%	0%	20%	0%	0%	0%	0%	0%
4	0%	0%	0%	50%	0%	0%	20%	0%	20%	10%
5	10%	0%	0%	10%	70%	0%	10%	0%	0%	0%
6	0%	0%	10%	10%	10%	40%	10%	0%	10%	10%
7	10%	0%	20%	20%	0%	0%	30%	0%	10%	10%
8	20%	0%	0%	10%	0%	20%	20%	10%	10%	10%
9	0%	0%	0%	10%	0%	10%	0%	10%	60%	10%
10	0%	20%	0%	0%	0%	20%	0%	0%	10%	50%

1. Load Spring Heavy, Males
2. Load Spring Heavy, Females
3. Load Spring Light, Males
4. Load Spring Light, Females
5. Speed Prop. Feel, Males
6. Speed Prop. Feel, Females
7. Conventional Reaction, Males
8. Conventional Reaction, Females
9. Control group, Males
10. Control group, Females



1. Load Spring Heavy, Males
2. Load Spring Heavy, Females
3. Load Spring Light, Males
4. Load Spring Light, Females
5. Speed Prop. Feel, Males
6. Speed Prop. Feel, Females
7. Conventional Reaction, Males
8. Conventional Reaction, Females
9. Control group, Males
10. Control group, Females

FIGURE 8. Group centroids plotted on the first discriminant function from Discriminant Analysis 14.

Males, therefore, with the exception of those in the Control group, are associated with making fewer coarse steering reversals on the M1 and trunk roads, driving more slowly and making more steering reversals in urban and suburban driving, driving faster and making fewer reversals on the last section of the route, driving faster and making many coarse steering reversals on other sections of the route and making fewer fine steering reversals overall. Females, with the exception of those in the Conventional Reaction group, are associated with making more coarse steering reversals on the M1 and some trunk roads, driving faster and making fewer steering reversals in urban and suburban driving, driving more slowly and making more steering reversals on the last section of the route, driving more slowly and making fewer coarse steering reversals on other sections of the route, and making more fine steering reversals overall.

A comparison of the results of the present analysis and Discriminant Analysis 6, in which the experimental groups were males and females, suggests that it is easier to discriminate between subjects' performance on Road-run 2 in terms of their sex than on the basis of the power steering group to which subjects were assigned. Inspection of Tables 33 and 17 indicates that the discriminant functions are very similar, and in both cases, males are associated with negative scores on the function and females are associated with positive scores. However, it can be seen from Figure 7 that two power steering groups, that is, males and females in the Control Group (groups nine and ten), and males and females in the Conventional Reaction Group (groups seven and eight), are not well separated on the first function derived in the present analysis. Thus, both males and females in the Control Group are associated with making more coarse steering reversals on the M1 and some trunk roads, driving faster and making fewer steering reversals on urban and suburban sections of the route, driving more slowly and making more steering reversals on the last section of the route, and making more fine steering wheel reversals generally. On the other hand, males, and to a lesser extent females in the Conventional Reaction group, were associated with making fewer coarse steering wheel reversals on the M1 and some trunk roads, driving more slowly and making more reversals on urban and suburban sections, driving faster and making fewer steering wheel reversals on the last section of the route, and with making fewer fine steering reversals generally. Again, it should be stressed that it is the combination of subjects' scores on each variable which allows a discrimination to be made between the experimental groups rather than scores on individual factors which, as the univariate F ratios indicate, are not always significantly different.

4.4.23 DISCRIMINANT ANALYSIS 15. DISCRIMINANT VARIABLES WERE NFACTORS 1F - 7F FROM TEST-TRACK 2 (EXPERIMENTAL POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE POWER STEERING GROUPS 1 - 10.

The means and standard deviations of groups' scores on NFactors 1F to 7F are given in Table 12 of Appendix N, where it can be seen that the differences between groups' mean scores were relatively small and the variability in scores was relatively large, and roughly comparable, for each group. The univariate F ratios indicate that the differences between groups' mean scores on NFactors 2F and 5F were significant at the 5% level. The binomial probability of two such significant differences from a total of sevenF tests is approximately .04, which suggests that this was not a purely chance result.

Pair-wise comparisons of the NFactor 2F means indicate that the differences between females in the Speed Proportional Feel group and males in the Load Spring Heavy and Control groups, and between males in the Load Spring Light group and Conventional Reaction groups were significant at the 5% level. Pair-wise comparisons of the NFactor 5F means indicate that females in both Load Spring groups differed significantly from males in the Load Spring Light group, Speed Proportional Feel group, Conventional Reaction group, and Control group, and from females in the Speed Proportional Feel group. Females in the Control group differed significantly from males in the Speed Proportional Feel group, Conventional Reaction group and Control group, and from females in the Speed Proportional Feel group. These differences were also significant at the 5% level.

The pattern of these differences indicates that in terms of NFactor 2F ("Time, all trials") and NFactor 5F ("Cones, Trial 3"), male power steering groups do not tend to differ from each other, female groups do tend to differ from each other and from males, and that some differences exist between males and females within power steering groups.

Although there were ten experimental groups in this analysis, there were only seven discriminant variables, NFactors 1F - 7F, with the result that seven discriminant functions were derived. From Table 35, it can be seen that only the first of these functions reached statistical significance, $p = .003$. A list of the highest loading variables on this function, their standardized weighting coefficients and the values of the group centroids on the function are given in Table 36.

From Table 35 it can be seen that the canonical correlation associated with the first discriminant function was .61, which indicates that approximately 37% of the variance in discriminant scores on the function is accounted for by the experimental 'groups' variable. The proportion of the total variance accounted for by the first function, indicated by the percent of trace, was 48%. It was possible to correctly classify an average of 33% of subjects on the basis of all seven discriminant functions, and the full classification matrix is given in Table 37. A plot of the group centroids on the first function is shown in Figure 9.

TABLE 35. Eigenvalues, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistics for the seven functions derived in Discriminant Analysis 15.

Function	Eigenvalue	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-square	Degrees of Freedom	Significance
1	.60	48	.61	.34	97.7	63	p = .003
2	.24	19	.44	.54	55.2	48	p = .223
3	.21	17	.42	.67	35.6	35	p = .441
4	.10	8	.30	.82	18.0	24	p = .805
5	.05	4	.21	.90	9.5	15	p = .848
6	.04	4	.20	.94	5.5	8	p = .699
7	.02	2	.14	.98	1.7	3	p = .642

It is again clear from an inspection of Figure 9, that subjects were more effectively discriminated between in terms of their sex than the power steering system to which they were assigned, when considering their test-track performance. Thus, all male subject groups were associated with positive scores and almost all of the females were associated with negative scores, with one group, the females in the Speed Proportional Feel condition, having a group centroid at .03 on the first discriminant function.

The variables associated with males' positive scores were hitting fewer cones on trials one and three, driving faster on all trials, responding more frequently to the subsidiary task and making more steering reversals on trial 1. Conversely, females' negative scores implied hitting more cones on trials one and three, driving more slowly on all trials, responding less frequently to the subsidiary task, and making fewer

TABLE 36. Discriminant Variables (NFactors from Test-track 2), Standardized weighting Coefficients and Group Centroids associated with the first function derived in Discriminant Analysis 15.

Variable	Variable Name	Standardized Weight
NFactor 5F	Cones, trial 3	- .76
NFactor 2F	Time, all trials	- .71
NFactor 6F	Cones, trial 1	- .44
NFactor 3F	Subsidiary task, all trials	.24
NFactor 4F	Steering wheel reversals, trial 1	.22
Group Centroids:		
	Group 1 Load Spring Heavy, Males	.42
	Group 2 Load Spring Heavy, Females	-1.04
	Group 3 Load Spring Light, Males	.73
	Group 4 Load Spring Light, Females	- .96
	Group 5 Speed Proportional Feel, Males	.45
	Group 6 Speed Proportional Feel, Females	.03
	Group 7 Conventional Reaction, Males	.43
	Group 8 Conventional Reaction, Females	- .65
	Group 9 Control Group, Males	1.22
	Group 10 Control Group, Females	- .62

steering wheel reversals on trial 1. These same variables appear in Table 19 associated with Discriminant Analysis 7, in which the Test-track 2 NFactors were analysed with respect to only males and females.

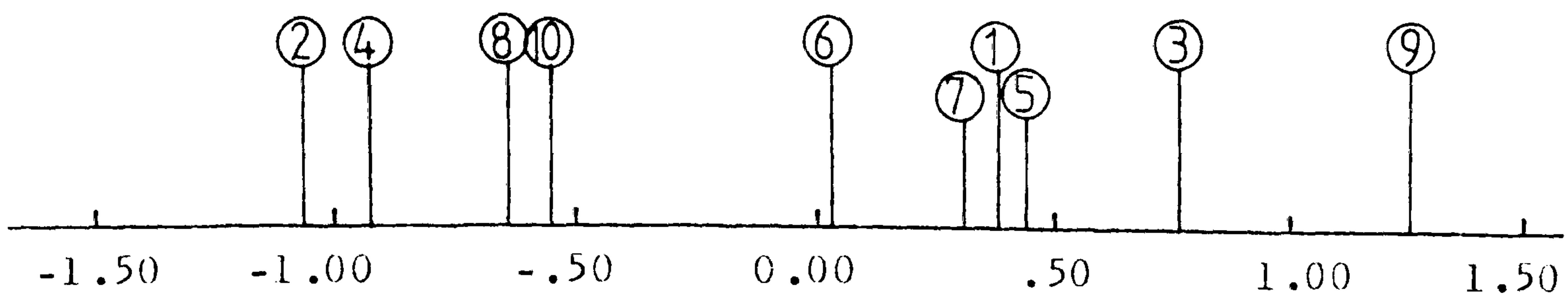
Although the two functions from the present analysis and Discriminant Analysis 7 are very similar, something can be said about the relative position of the power steering groups within the male/female groups on the function shown in Figure 9.

TABLE 37. Percent of cases correctly and incorrectly classified on the basis of the seven functions derived in Discriminant Analysis 15.

Actual Group Membership	Predicted Group Membership									
	1	2	3	4	5	6	7	8	9	10
1	40%	10%	0%	0%	30%	10%	10%	0%	0%	0%
2	0%	40%	10%	30%	0%	0%	0%	10%	0%	10%
3	0%	0%	30%	10%	30%	10%	20%	0%	0%	0%
4	0%	10%	10%	30%	10%	0%	10%	20%	10%	0%
5	20%	10%	10%	0%	0%	20%	10%	10%	20%	0%
6	0%	10%	10%	0%	10%	50%	10%	10%	0%	0%
7	0%	10%	20%	10%	20%	20%	20%	0%	0%	0%
8	0%	0%	0%	0%	20%	0%	0%	60%	0%	20%
9	10%	0%	10%	0%	30%	0%	10%	0%	40%	0%
10	0%	10%	10%	20%	20%	10%	0%	10%	0%	20%

Group 1 Load Spring Heavy, Males
Group 2 Load Spring Heavy, Females
Group 3 Load Spring Light, Males
Group 4 Load Spring Light, Females
Group 5 Speed Proportional Feel, Males
Group 6 Speed Proportional Feel, Females
Group 7 Conventional Reaction, Males
Group 8 Conventional Reaction, Females
Group 9 Control Group, Males
Group 10 Control Group, Females

For example, if the function is thought of as uni-polar, irrespective of the fact that males and females tend towards the extremes, power steering systems can be placed along a single dimension of 'steering accuracy, speed and spare mental capacity'. Although males on the whole perform 'better' in this sense than females, as they are associated with positive scores on the dimension, it can be



1. Load Spring Heavy, Males
2. Load Spring Heavy, Females
3. Load Spring Light, Males
4. Load Spring Light, Females
5. Speed Prop. Feel, Males
6. Speed Prop. Feel, Females
7. Conventional Reaction, Males
8. Conventional Reaction, Females
9. Control group, Males
10. Control group, Females

FIGURE 9. <u>Group centroids plotted on the first discriminant function from Discriminant Analysis 15.</u>

seen that the Load Spring Heavy group is 'worse' than the others for female subjects, and the Conventional Reaction group is 'worse' than the others for males.

Proceeding in this way, we can see that among the females, the Load Spring Heavy and Load Spring Light groups (groups 2 and 4), performed least well, the Conventional Reaction and Control groups (groups 8 and 10), performed better, with the best performance among females on the new single dimension coming from the Speed Proportional Feel group (group 6). Among the males, the Load Spring Heavy, Conventional Reaction and Speed Proportional Feel groups (groups 1, 5 and 7), performed least well, the Load Spring Light group (group 3), performed better, with the Control group (group 9), performing best.

Without exception, none of the power steering characteristics are ranked in the same order from 'good' to 'bad' for the two sexes.

4.4.24 DISCRIMINANT ANALYSIS 16. DISCRIMINANT VARIABLES WERE NFACTORS 1D - 7F FROM QUESTIONNAIRE 'C' ROAD-RUN 2 AND TEST-TRACK 2 (EXPERIMENTAL POWER STEERING IN USE). EXPERIMENTAL GROUPS WERE POWER STEERING GROUPS 1 - 10.

The means and standard deviations of groups' scores on NFactors 1D to 17D, 1E to 15E and 1F to 7F have already been given in Appendix N, Tables 10, 11 and 12 respectively. The univariate F ratios, also reported in earlier sections, indicate that groups' mean scores on NFactors 2E, 9E, 2F and 5F were significant at either the 5% or 1% levels. The binomial probability of four such significant results from a total of thirty nine F tests is approximately .05, which indicates that this was unlikely to have been a purely chance result.

The pattern of significant results from the pair-wise comparisons of groups' mean scores on these variables which were reported in earlier sections, suggest that males drove differently from females on both Road-run 2 and Test-track 2, that males in the Control group drove differently from males in the other power steering groups on the road-run, and that females in each of the power steering groups drove differently from one another on the test-track.

Of the nine discriminant functions derived in this analysis, it can be seen from Table 36 that the first two functions were significant at the .1% level, and that the third function was marginally significant, $p = .087$. The canonical correlations associated with the first three functions were .76, .74 and .65, which indicates that approximately 58%, 55% and 42% respectively of the variance in discriminant scores is accounted for by the experimental 'groups' variable. The proportion of the total variance accounted for by the first three functions, or the percent of trace, was 29%, 26% and 16% respectively.

A list of the highest loading variables on each function, their standardized weighting coefficients and the values of the group centroids on each function is given in Table 39. It was possible to correctly classify an average of 63% of subjects on the basis of the nine functions derived, and the full classification matrix is given in Table 40. In Figures 10, 11 and 12, the group centroids are plotted as cartesian coordinates on each pair of functions formed from the first three discriminant functions derived in the analysis.

TABLE 38. Eigenvalues, Percent of Trace, Canonical Correlation, Wilk's Lambda and Chi-square statistics for the nine functions derived in Discriminant Analysis 16.

Function	Eigenvalue	Percent of Trace	Canonical Correlation	Wilk's Lambda	Chi-square	Degrees of Freedom	Significance
1	1.33	29	.76	.03	284.8	180	$p < .001$
2	1.18	26	.74	.08	213.6	152	$p = .001$
3	.72	16	.65	.17	148.0	126	$p = .087$
4	.49	11	.57	.30	102.2	102	$p = .479$
5	.34	7	.50	.44	68.5	80	$p = .816$
6	.22	5	.42	.59	43.9	60	$p = .942$
7	.18	4	.39	.72	27.5	42	$p = .959$
8	.12	3	.33	.85	13.8	26	$p = .976$
9	.05	1	.22	.95	4.1	12	$p = .982$

Although the results of previous discriminant analyses suggest that it is easier to discriminate between males and females than to discriminate between the five power steering groups on the basis of the NFactors from the second half of the experiment, the first function derived in the present analysis does provide an effective means of discriminating between the power steering groups.

TABLE 39. Discriminant Variables (NFactors from Questionnaire 'C', Road-run 2 and Test-track 2), standardized weighting coefficients and group centroids associated with the first three functions derived in Discriminant Analysis 16.

Variable	Variable Name	Standardized Weights
Function 1		
NFactor 9E	Time, coarse steer, fine steer, Bedford to Test Area	- .92
NFactor 2E	Coarse steer, especially straight roads	- .67
NFactor 8D	Steering too light, no different	- .67
NFactor 14E	Time, coarse steer, fine steer, Ampthill to Flitwick	.64
NFactor 5F	Cones, trial 3	.56
NFactor 10D	Sensitivity, response, easy to position	.46
Function 2		
NFactor 10D	Sensitivity, response, easy to position	- .75
NFactor 5F	Cones, trial 3	- .69
NFactor 2D	Difficult to maintain lane position difficult to control during lane-changes, lack of confidence at speed	- .65
NFactor 2F	Time, all trials	- .63
NFactor 9D	Holding back less often, lack of feel, more confidence at high speeds than at low speeds	- .61
NFactor 3F	Subsidiary task, all trials	.40
NFactor 4F	Coarse steer, fine steer, trial 1	.40
Function 3		
NFactor 10D	Sensitivity and response, easy to position	1.25
NFactor 5D	Driving faster, overtaking more, easier to control	.64
NFactor 6E	Time, coarse steer, fine steer, Ampthill	- .57
NFactor 2D	Difficult to maintain lane position, difficult to control during lane-changes, lack of confidence at high speed	- .57
NFactor 16D	Less play in steering, taking longer at mini-roundabouts	- .46

TABLE 39 contd.

Group Centroids	Discriminant Function		
Groups:	1	2	3
1 Load Spring Heavy, Males	2.06	.41	1.54
2 Load Spring Heavy, Females	.63	- .22	.03
3 Load Spring Light, Males	.60	1.36	-1.08
4 Load Spring Light, Females	.20	-1.29	.18
5 Speed Proportional Feel, Males	- .14	1.15	.14
6 Speed Proportional Feel, Females	-1.50	.19	.32
7 Conventional Reaction, Males	.34	.34	- .53
8 Conventional Reaction, Females	.56	-1.19	-1.46
9 Control Group, Males	-1.90	.99	.30
10 Control Group, Females	- .90	-1.75	.57

From Figure 10 it can be seen that both males and females in the Load Spring Heavy group (groups 1 and 2), males and females in the Load Spring Light group (groups 3 and 4), and males and females in the Conventional Reaction group (groups 7 and 8) are associated with positive scores on the first function, while males and females in the Speed Proportional Feel group (groups 5 and 6) and males and females in the Control group (groups 9 and 10) are associated with negative scores on the first function. Although differences remain between the sexes within power steering groups, therefore, something can be said about power steering systems per se on the basis of the first discriminant function.

The variables associated with the Load Spring Heavy group, Load Spring Light group and the Conventional Reaction group were driving quickly and making fewer steering wheel reversals on the last section of the route (a trunk road), with making fewer coarse steering reversals on the M1 and trunk roads, commenting on the steering's being too heavy and different, driving more slowly and making more steering reversals on a suburban section of the route, hitting more cones on trial 3 of the test-track, and with commenting that the steering was

TABLE 40. Percent of cases correctly and incorrectly classified on the basis of the nine functions derived in Discriminant Analysis 16.

Actual Group Membership	Predicted Group Membership 1	2	3	4	5	6	7	8	9	10
1	80%	0%	10%	10%	0%	0%	0%	0%	0%	0%
2	10%	40%	20%	10%	20%	0%	0%	0%	0%	0%
3	0%	10%	50%	0%	10%	10%	20%	0%	0%	0%
4	10%	10%	0%	50%	0%	0%	10%	10%	0%	10%
5	10%	0%	10%	0%	60%	20%	0%	0%	0%	0%
6	0%	0%	0%	0%	20%	80%	0%	0%	0%	0%
7	0%	10%	10%	0%	0%	0%	60%	10%	10%	0%
8	0%	0%	0%	10%	0%	0%	0%	70%	0%	20%
9	0%	0%	10%	0%	10%	0%	10%	0%	70%	0%
10	0%	0%	0%	20%	0%	0%	0%	0%	10%	70%

Groups:

1 Load Spring Heavy, Males
2 Load Spring Heavy, Females
3 Load Spring Light, Males
4 Load Spring Light, Females
5 Speed Proportional Feel, Males
6 Speed Proportional Feel, Females
7 Conventional Reaction, Males
8 Conventional Reaction, Females
9 Control Group, Males
10 Control Group, Females

more responsive, more sensitive and easier to position. The variables associated with the Speed Proportional Feel group and the Control group were driving more slowly and making more steering reversals on the last section of the route (a trunk road), making more coarse steering reversals on the M1 and trunk roads, commenting that the steering was too light and no different, driving faster and making fewer steering

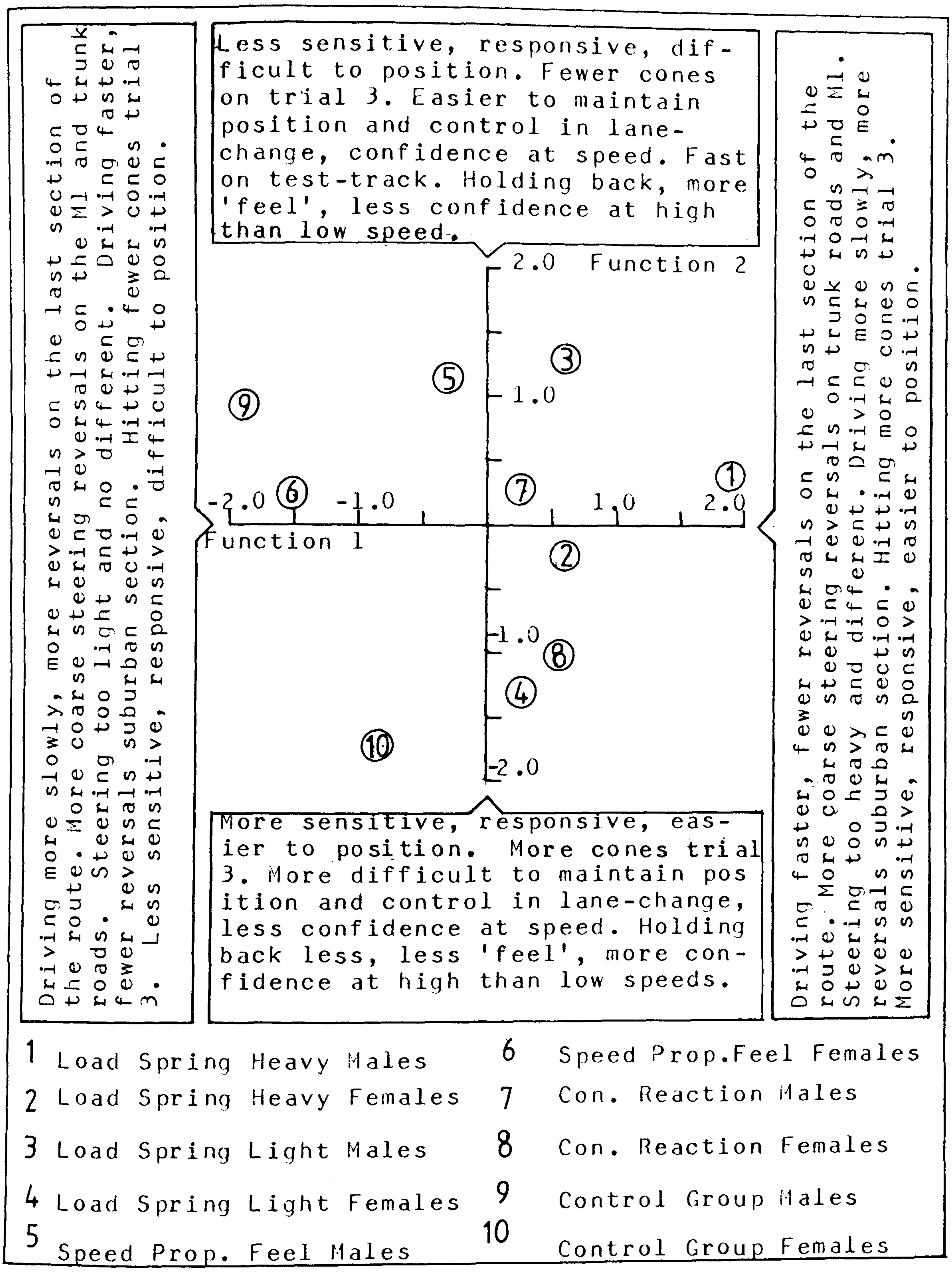


FIGURE 10. Graphic representation of discriminant functions 1 and 2 from Discriminant Analysis 16. The discriminant variables associated with positive and negative scores on each function are shown at the ends of the appropriate axes.

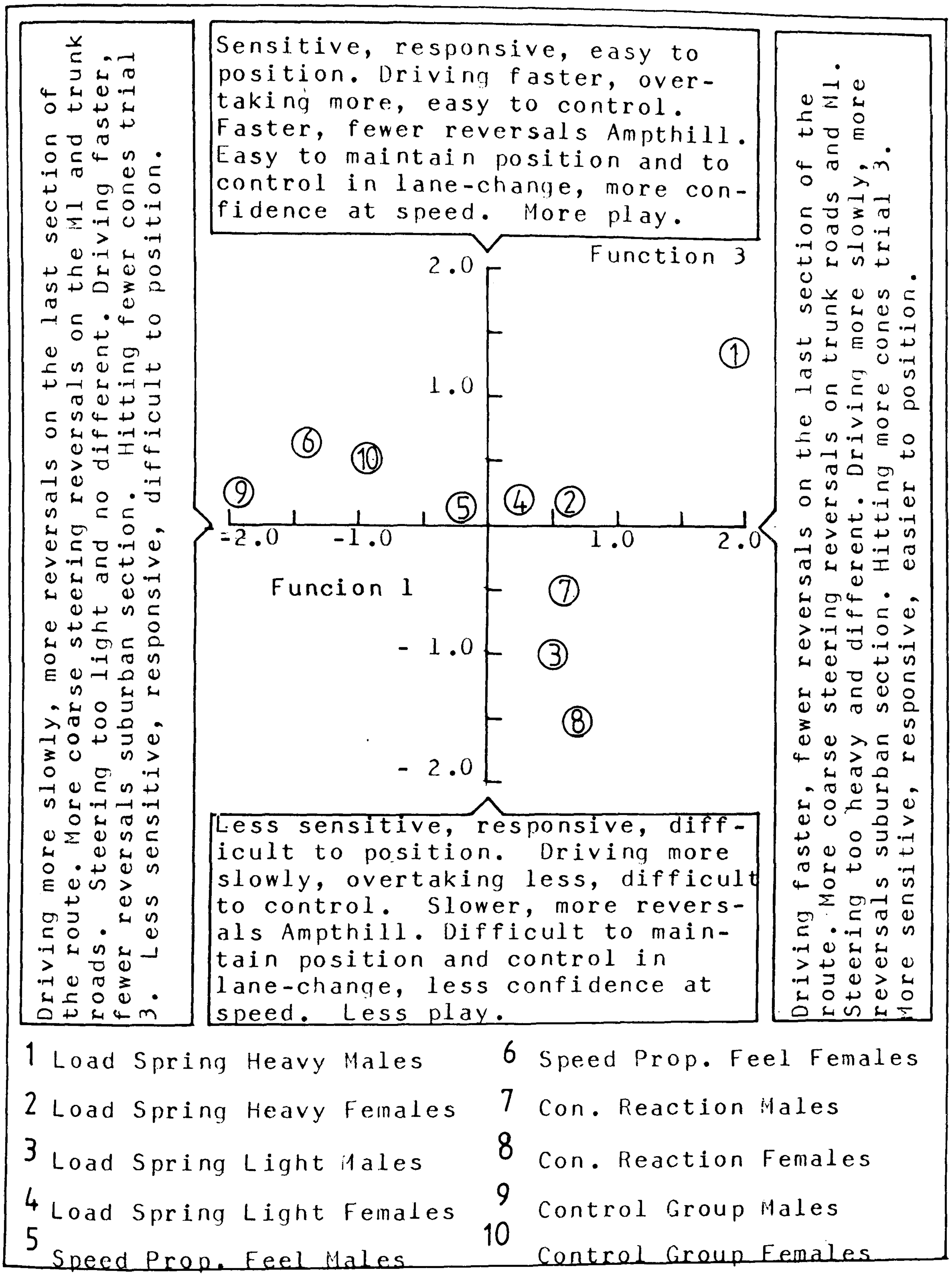


FIGURE 11. Graphic representation of discriminant functions 1 and 3 from Discriminant Analysis 16. The discriminant variables associated with positive and negative scores on each function are shown at the ends of the appropriate axes.

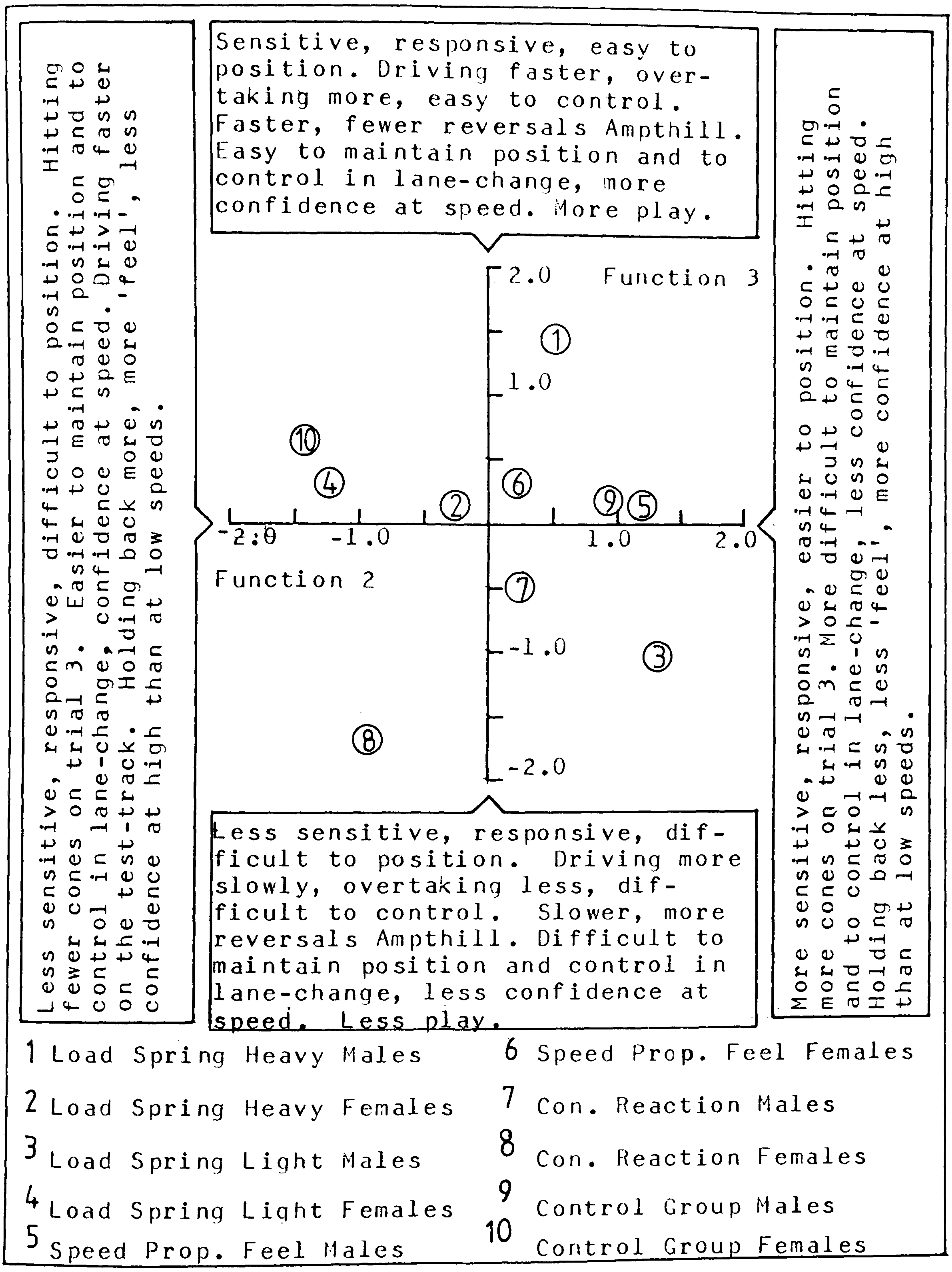


FIGURE 12. Graphic representation of discriminant functions 2 and 3 from Discriminant Analysis 16. The discriminant variables associated with positive and negative scores on the function are shown at the ends of the appropriate axes.

reversals on a suburban section of the route, hitting fewer cones on the test-track and commenting that the steering was less responsive, less sensitive and harder to position.

The difference between power steering groups described above seemed to be based upon the reaction of groups to different driving situations. Thus, the Load Spring Heavy, Load Spring Light and Conventional Reaction groups performed differently on straight high speed roads, tending to drive faster and make fewer reversals, than the Speed Proportional Feel group and Control group. However, the Load Spring groups and Conventional Reaction group tended to drive more slowly and make more reversals on suburban, low speed, sections and to hit more cones on the test-track than did the Speed Proportional Feel and Control groups.

Discriminant function 2 effectively discriminates between those groups which were not well separated on function 1, that is, groups 2, 3 and 8, and groups 4 and 7. It also tends to discriminate between groups on the basis of sex, so that the males are associated with positive scores and females, with the exception of those in the Speed Proportional Feel group, are associated with negative scores.

Thus, male subjects, and females in the Speed Proportional Feel group, tended to describe the steering as having little sensitivity and responsiveness, difficult to position, hit fewer cones on the test-track, found it easy to maintain their lane position and to control the car, had confidence in the steering at high speed, drove faster on the test-track, held back more often, responded more frequently to the subsidiary task and made more steering reversals on trial 1. Females, with the exception of those in the Speed Proportional Feel group, tended to find the steering sensitive and responsive, easy to position, hit more cones and drove more slowly on the test-track, found it difficult to maintain their lane position and expressed a lack of confidence at speed, held back less, responded less frequently to the subsidiary task, and made fewer steering reversals on the first trial of the test-track session.

The variables associated with a high positive score on function 3 are sensitivity, responsiveness, ease of positioning, driving faster and overtaking more, ease of control, driving faster and making fewer steering wheel reversals in Ampthill, (an urban section), ease of maintaining lane position and confidence at high speed, and more play in the steering. Variables associated with a high negative score are a lack of sensitivity and responsiveness in the steering, difficulty in positioning the car, driving more slowly, overtaking less and difficulty in controlling the car, driving more slowly and making more steering reversals in Ampthill, difficulty in maintaining lane position and lack of confidence at speed, and less play in the steering.

Discriminant function 3 seems to represent a more general dimension, providing an overall description of power steering system performance irrespective of the specific driving situation. Essentially, the positive scores of the male Load Spring Heavy group, female Load Spring Light group, both males and females in the Speed Proportional Feel group and Control group may be interpreted as generally favourable, while the negative scores of the males in the Load Spring Light group, and both males and females in the Conventional Reaction group may be interpreted as generally unfavourable. (Females' scores in the Load Spring Heavy group may be interpreted as neither favourable nor unfavourable on this general dimension). The fact that discriminant function three was only marginally significant, p = .087, and that it accounts for only 16% of the total variance, indicates that this function does not add greatly to the ability to discriminate between subjects on the basis of the NFactors from the second half of the study.

4.4.25 INTRODUCTION TO THE ANALYSIS OF VARIANCE OF TEST-TRACK DATA

It was stated in the Methodology section that, in order for subsidiary task performance to be interpreted in terms of the 'spare mental capacity' model, it is necessary to assume that performance of the subsidiary task does not affect performance on the primary task. It was argued that, as long as primary task performance remains constant, any change in the demands of the primary task under different experimental treatments will be reflected by fluctuations in subsidiary task performance. If, however, primary task performance also varies under different treatment conditions, performance on the subsidiary task can no longer be taken as a legitimate measure of 'spare mental capacity'.

Since subsidiary task responses were shown to be useful in discriminating between experimental groups in the previous analyses, it was felt to be important to investigate further the role of the subsidiary task variable in relation to the dependent and independent measures on the test-track. The first question to be asked of the test-track data, therefore, was: "Does responding to the subsidiary task affect drivers' performance on any of the primary task measures?"

To answer this question, a number of analyses of variance were conducted on the data from both Test-track 1 and Test-track 2 sessions. The analyses were carried out using the GENSTAT statistical package developed at the Rothamsted Experimental Station (Alvey et al, 1977) version 4.01. The GENSTAT package was run on the same computer at the Manchester Regional Computing Centre as the SPSS package used previously. All analyses were five-way 5x2x4x2x10, partially hierarchical designs. The factors were power steering (Power), subjects' sex (Sex), order of task (Order), type of task, that is, subsidiary or no subsidiary task (Task) and subjects (Subject) respectively, the Subject factor being nested under both Power and Sex. The first level of the Order factor was defined in terms of subjects' performance on trials 1 and 2, the second level of the Order factor was defined in terms of subjects' performance on trials 3 and 4, and so on to level four of the Order factor, which comprised the combined data from trials 7 and 8. Each level of Order contained Task 1 (no subsidiary task) and Task 2 (subsidiary task) data, therefore. All factors were considered fixed except Subjects which was considered random. A schematic representation of the design appears in Table 41.

TABLE 41. <u>Schematic diagram of the five-way analysis of variance design used to analyse data from test-track sessions 1 and 2.</u>

			A_1	A_2	A_3	A_4	A_5
B_1	C_1	D_1 D_2	S1-S10	S21-S30	S41-S50	S61-S70	S81-S90
	C_2	D_1 D_2	S1-S10	S21-S30	S41-S50	S61-S70	S81-S90
	C_3	D_1 D_2	S1-S10	S21-S30	S41-S50	S61-S70	S81-S90
	C_4	D_1 D_2	S1-S10	S21-S30	S41-S50	S61-S70	S81-S90
B_2	C_1	D_1 D_2	S11-S20	S31-S40	S51-S60	S71-S80	S91-S100
	C_2	D_1 D_2	S11-S20	S31-S40	S51-S60	S71-S80	S91-S100
	C_3	D_1 D_2	S11-S20	S31-S40	S51-S60	S71-S80	S91-S100
	C_4	D_1 D_2	S11-S20	S31-S40	S51-S60	S71-S80	S91-S100

A = Power, B = Sex, C = Order, D = Task, S = Subjects

Separate five-way analyses of variance were carried out for each of the three dependent variables, Time, Fine Steer and Coarse Steer, and for both Test-track 1 and Test-track 2 sessions. The number of cones hit by subjects was not included in these analyses because the values of this variable were too small to be used, that is, many cells contained zeroes. The results of the six analyses of variance are given in the following sections.

4.4.26 ANALYSIS OF VARIANCE 1. DATA ARE FROM TEST-TRACK 1, DEPENDENT VARIABLE: TIME

The summary table for Analysis of Variance 1 is given in Table 42, where it can be seen that there were significant main effects of Sex, ($F = 11.0$, d.f. 1 and 90, $p < .01$), Order ($F = 132.8$, d.f. 3 and 270, $p < .01$), and Task ($F = 15.6$, d.f. 1 and 90, $p < .01$), and a significant Order by Task interaction ($F = 41.6$, d.f. 3 and 282, $p < .01$).

An estimate of the degree of association between dependent and independent variables was made for all significant effects following Hays (1973) p.485, and values of the estimated index ω^2 are included in Table 42.

Means for the significant effects are given in Table 43, and the means for the significant Order by Task interaction are represented graphically in Figure 13.

Although significant, the effect of subjects' sex on mean driving time is relatively unimportant. The estimated degree of association, est $\omega^2 = .09$, suggests that only about 9% of the variance in driving time is accounted for by Sex. Inspection of the means in Table 43 shows that males drove faster (that is, had a lower mean driving time) than females. This confirms the findings of the previous discriminant analyses of test-track data.

The overall main effect of Order can be seen to be quite strong, in that approximately 56% of variance in driving time is accounted for by the Order effect when considered across all levels of the other factors (est $\omega^2 = .56$). Inspection of the means in Table 43 shows that driving speeds tended to increase over subsequent orders, as might be expected. However, the significant and fairly strong Order by Task interaction (est $\omega^2 = .28$), indicates that the Order effect also depends upon the type of task being performed, and from Figure 13 it can be seen how these two factors interact. Although the overall effect of Order is to reduce driving time over trials, it can be seen that when the Task factor is taken into account, there is a distinct

TABLE 42. Summary table for Analysis of Variance 1. Data are from Test-track 1, dependent variable: Time.

Source	SS	DF	MS	F	est.ω^2
Power	13493.8	4	3373.4	0.61	
Sex	60795.8	1	60795.8	11.00**	.09
Power x Sex	19841.8	4	4960.5	0.90	
Residual	497491.2	90	5527.7	77.49	
Order	65498.0	3	21832.6	132.80**	.56
Power x Order	2696.6	12	224.7	1.37	
Sex x Order	508.5	3	169.5	1.03	
Power x Sex x Order	2366.1	13	197.2	1.20	
Residual	44387.0	270	164.4	2.30	
Task	1485.1	1	1485.1	15.62**	.12
Power x Task	364.8	4	91.2	0.96	
Sex x Task	44.2	1	44.2	0.46	
Power x Sex x Task	727.8	4	182.0	1.91	
Residual	3554.4	90	95.0	1.33	
Order x Task	8903.2	3	2967.7	41.60**	.28
Power x Order x Task	836.2	12	69.7	0.98	
Sex x Order x Task	528.1	3	176.0	2.47	
Residual	20115.3	282	71.3		
Totals	748638.0	799			

**Indicates a value of F significant at the 1% level.

TABLE 43. Table of means for the significant main effects and interations from Analysis of Variance 1. Data are from Test-track 1, dependent variable: Time.

Factor	Level			
Sex	Males 107.28		Females 124.71	
	1	2	3	4
Order	130.74	115.51	110.84	106.88
Task	No subsidiary task (1) 114.63		Subsidiary task (1) 117.36	
Task	No subsidiary task		Subsidiary task	
Order	(1)		(2)	
1	134.45		127.04	
2	115.06		115.97	
3	106.21		115.48	
4	102.81		110.94	

'plateau' between levels 2 and 3 of the Order factor when the subsidiary task (Task 2) is present. Differences between all pairs of means* across Order were significant for both tasks, $p < .01$, except that between Orders 2 and 3 for Task 2, i.e. over the 'plateau' referred to above.

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*Differences between individual means were tested by the use of the Newman - Keuls procedure described in Winer (1971) pp. 191-196.

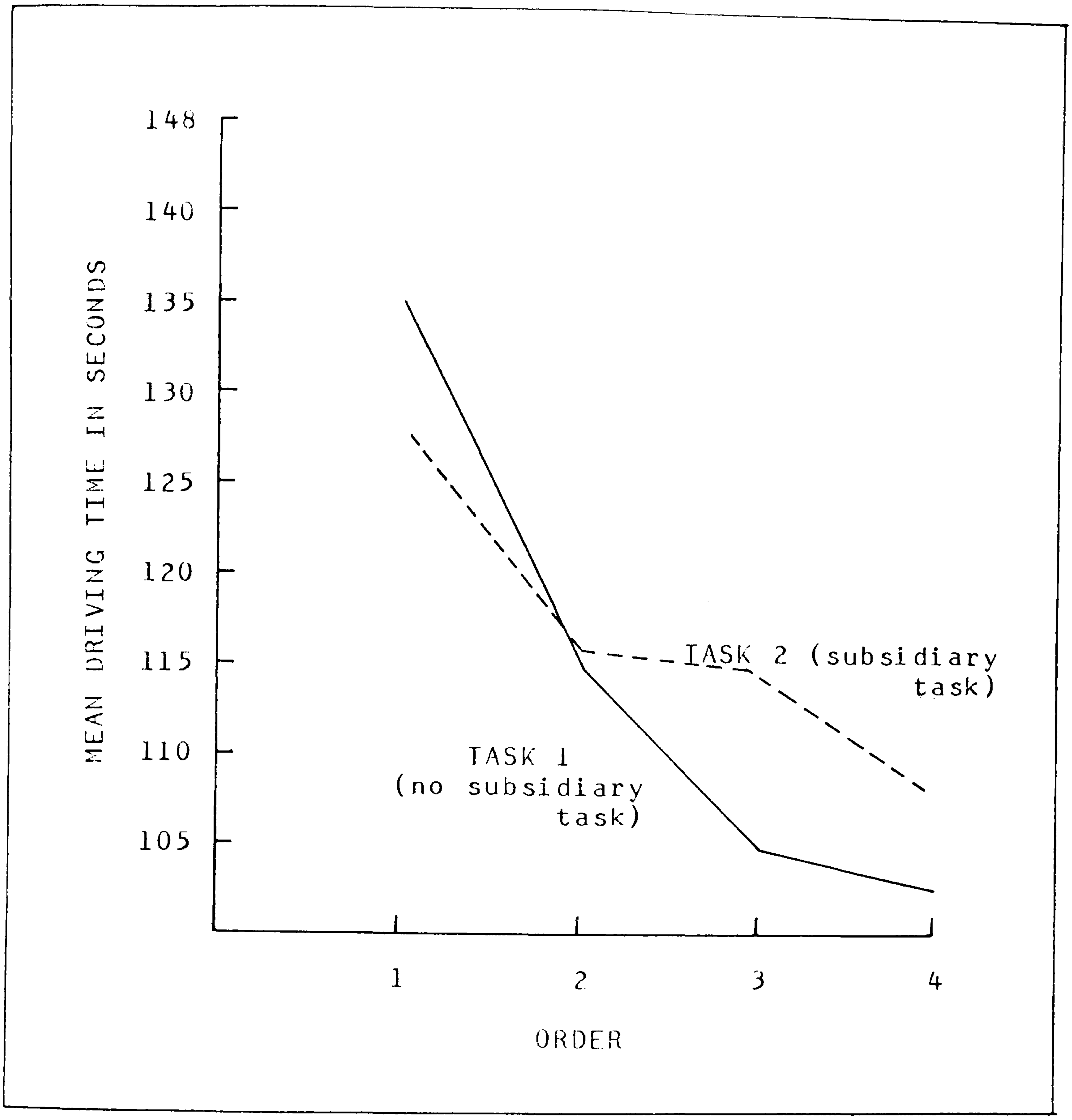


FIGURE 13. Graphic representation of the Order by Task interaction from Analysis of Variance 1. Data are from Test-track 1, dependent variable: Time.

Similarly, reference to the means associated with the significant overall effect of Task ($p < .01$, est $\omega^2 = .12$), indicates that subjects drove faster when no subsidiary task was administered. This must also be interpreted in the light of the Order by Task interaction depicted in Figure 13, however, which shows that subjects drove faster under Task 1 conditions on some orders but not on others. Thus, subjects drove significantly faster when responding to the subsidiary task on Orders 3 and 4. The difference in subjects' driving speeds on Order 2 was not significant.

The differential effect of the subsidiary task on driving speed with respect to Order is probably due to the fact that the effect of subsidiary task on Order 1 was confounded by a strong learning effect. That is to say, subjects were likely to have driven relatively slowly on the first test-track trial irrespective of the fact that no subsidiary task was administered. Having become relatively familiar with the driving task on the first trial, subjects were able to drive significantly faster despite being required to respond to the subsidiary task on the second trial. A strong learning effect associated with the driving task on the first two trials would, therefore, account for the observed Task by Order interaction seen for Order 1.

The existence of significant Task and Task by Order effects indicates that the presence of the subsidiary task did affect the primary task measure of driving time on the first test-track session.

4.4.27 ANALYSIS OF VARIANCE 2. DATA ARE FROM TEST-TRACK 1, DEPENDENT VARIABLE: FINE STEER.

The summary table for Analysis of Variance 2 is given in Table 44, where it can be seen that there were significant overall main effects of Order ($F = 93.2$, d.f. 3 and 270, $p < .01$), Task ($F = 96.3$, d.f. 1 and 90, $p < .01$), and a significant Sex by Order interaction effect ($F = 2.64$, d.f. 3 and 270, $p < .05$). Values of estω^2 were calculated as before and are also shown in Table 44.

TABLE 44. Summary table for Analysis of Variance 2. Data are from Test-track 2, dependent variable: Fine steer.

Source	SS	DF	MS	F	est.ω^2
Power	1145.0	4	286.3	0.61	
Sex	0.0	1	0.0	0.00	
Power x Sex	1573.3	4	393.3	0.84	
Residual	42072.5	90	467.5	18.96	
Order	8718.9	3	2906.3	93.18**	.48
Power x Order	347.0	12	28.9	0.93	
Sex x Order	247.1	3	82.4	2.64*	.01
Power x Sex x Order	88.7	12	7.4	0.24	
Residual	8421.5	270	31.2	1.26	
Task	2926.1	1	2926.1	96.30**	.47
Power x Task	188.9	4	47.2	1.55	
Sex x Task	1.6	1	1.6	0.05	
Power x Sex x Task	312.4	4	78.1	2.57	
Residual	2734.6	90	30.4	1.23	
Order x Task	66.1	3	22.0	0.89	
Power x Order x Task	84.6	12	7.0	0.29	
Sex x Order x Task	38.8	3	12.9	0.52	
Residual	6953.8	282	24.7		
Totals	75921.1	799			

* Indicates a value of F significant at the 5% level.

** Indicates a value of F significant at the 1% level.

Means for the significant effects are given in Table 45, and the means for the significant Sex by Order interaction are represented graphically in Figure 14.

The significant overall main effect of Order is relatively strong, est ω^2 = .48, indicating that approximately 50% of the variance in subjects' fine steering wheel reversals is accounted for by the Order effect. Inspection of the means in Table 45 indicates that overall, the effect of Order was to reduce the number of fine steering reversals.

Although the Sex by Order interaction was found just to be significant at the five percent level, tests carried out between each pair of Sex means at each level of Order failed to reach significance. The existence of this very weak effect est ω^2 = .01, must be regarded with suspicion therefore. Individual tests carried out between each pair of means within each level of Sex, however, were significant in all cases, except for those of the difference in males' and females' fine steering reversals between Orders 2 and 3 and Orders 3 and 4, thus confirming the existence of an Order effect.

The overall main effect of Task was also relatively strong, est ω^2 = .47, and reference to the table of means indicates that the effect of the subsidiary task (Task 2) was to increase the numbers of fine steering wheel reversals made by drivers.

TABLE 45. Table of means for the significant main effects and interactions from Analysis of Variance 2. Data are from Test-track 1, dependent variable: Fine steer.

Factor	Level			
	1	2	3	4
Order	44.70	39.52	37.88	35.76
	No subsidiary task		Subsidiary task	
	(1)		(2)	
Task	37.56		41.38	
Sex	Males		Females	
	(1)		(2)	
Order				
1	44.20		45.20	
2	40.41		38.63	
3	37.45		38.32	
4	35.83		37.70	

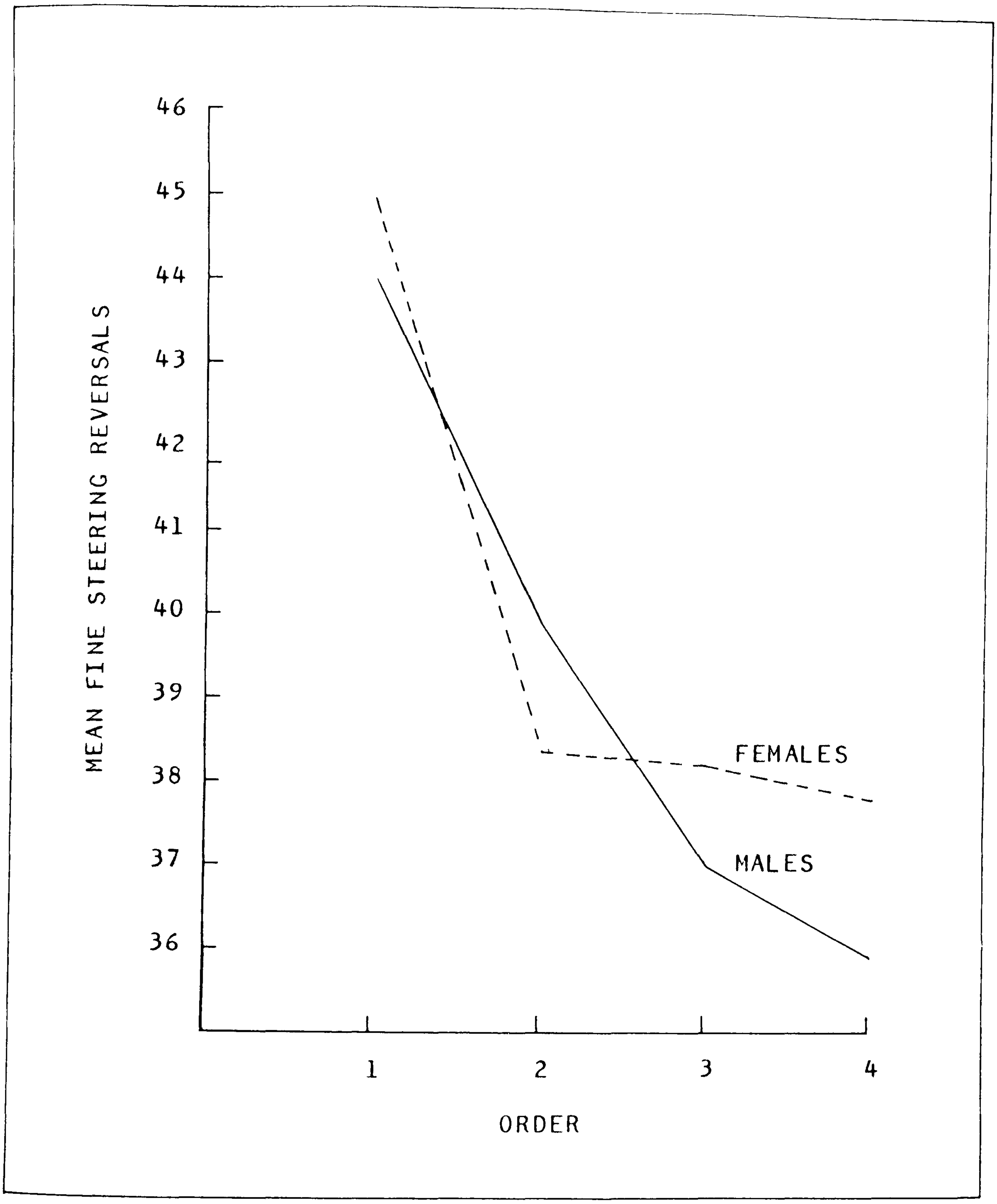


FIGURE 14. Graphic representation of the Sex by Order interaction from Analysis of Variance 2. Data are from Test-track 1, dependent variable: Fine Steer.

4.4.28 ANALYSIS OF VARIANCE 3. DATA ARE FROM TEST-TRACK 1, DEPENDENT VARIABLE: COARSE STEER.

The summary table for Analysis of Variance 3 is given in Table 46, where it can be seen that the overall main effects of Order ($F = 58.0$, d.f. 3 and 270, $p < .01$), and Task ($F = 16.0$, d.f. 1 and 90, $p < .01$) were significant, together with two interactions, Sex by Task ($F = 4.7$, d.f. 1 and 90, $p < .05$), and Order by Task ($F = 9.1$, d.f. 3 and 282, $p < .01$).

Means for the significant effects are given in Table 47 and the means for the Order by Task interaction are plotted graphically in Figure 15.

The overall effect of Order was again found to be relatively strong, est $\omega^2 = .37$, and inspection of the means in Table 47 indicates that the number of coarse steering wheel reversals declined over Order. Each pair of these means is significantly different at the one percent level.

A significant but weak Order by Task interaction, est $\omega^2 = .07$, also indicates that the Order effect differed with respect to the presence or absence of the subsidiary task, however, and this is shown clearly in Figure 15. Although the overall effect of Order is one of a steady reduction in the number of coarse steering reversals over subsequent orders, there is a noticeable 'levelling off' between Orders 2 and 3 when the subsidiary task was administered. Furthermore, the initially lower mean number of reversals when the subsidiary task was administered for Order 1 becomes a relatively higher mean number of reversals at Order 4. When tested individually, comparisons between pairs of means at each level of Order were all significant for both levels of Task at the one percent or five percent levels. Comparisons between all pairs of means at each level of Task were also significant at the one percent or five percent level, except those between Orders 3 and 4 when no subsidiary task was administered (Task 1), and those between Orders 2 and 3 when the subsidiary task was administered (Task 2).

TABLE 46. Summary table for Analysis of Variance 3. Data are from Test-track 1, dependent variable: Coarse steer.

Source	SS	DF	MS	F	est.ω^2
Power	36.3	4	9.0	0.13	
Sex	33.6	1	33.6	0.48	
Power x Sex	197.6	4	49.4	0.71	
Residual	6266.3	90	69.6	10.43	
Order	1245.5	3	415.1	57.98**	.37
Power x Order	65.8	12	5.4	0.76	
Sex x Order	13.8	3	4.6	0.64	
Power x Sex x Order	47.9	12	3.9	0.55	
Residual	1933.1	270	7.1	1.07	
Task	122.5	1	112.5	16.00**	.12
Power x Task	26.6	4	6.6	0.94	
Sex x Task	32.8	1	32.8	4.66*	.03
Power x Sex x Task	58.7	4	14.6	2.08	
Residual	632.5	90	7.0	1.05	
Order x Task	182.2	3	60.7	9.10**	.07
Power x Order x Task	118.7	12	9.9	1.48	
Sex x Order x Task	10.2	3	3.4	0.51	
Residual	1882.4	282	6.6		
Totals	12897.2	799			

* Indicates a value of F significant at the 5% level.

** Indicates a value of F significant at the 1% level.

The fact that the mean number of reversals was found to be significantly higher when no subsidiary task was administered (Task 1), than it was when subjects responded to the subsidiary task (Task 2) on Order 1, but not on Orders 2, 3 and 4, is again likely to have been caused by a differential learning effect on trials 1 and 2. That is to say, subjects were sufficiently familiar with the driving task on trial 2, in which the subsidiary task was administered, that they were able to make fewer steering reversals than they had made on trial 1, when no subsidiary task was administered.

TABLE 47. Table of means for the significant main effects and interactions from Analysis of Variance 3. Data are from Test-track 1, dependent variable: Coarse steer.

Factor	Level			
	1	2	3	4
Order	21.96	19.96	19.34	18.60
	No subsidiary task (1)		Subsidiary task (2)	
Task	19.59		20.34	
Task / Sex	No subsidiary task (1)		Subsidiary task (2)	
Males (1)	19.59		20.75	
Females (2)	19.59		19.93	
Task / Order	No subsidiary task (1)		Subsidiary task (2)	
1	22.36		21.56	
2	19.59		20.34	
3	18.51		20.18	
4	17.91		19.29	

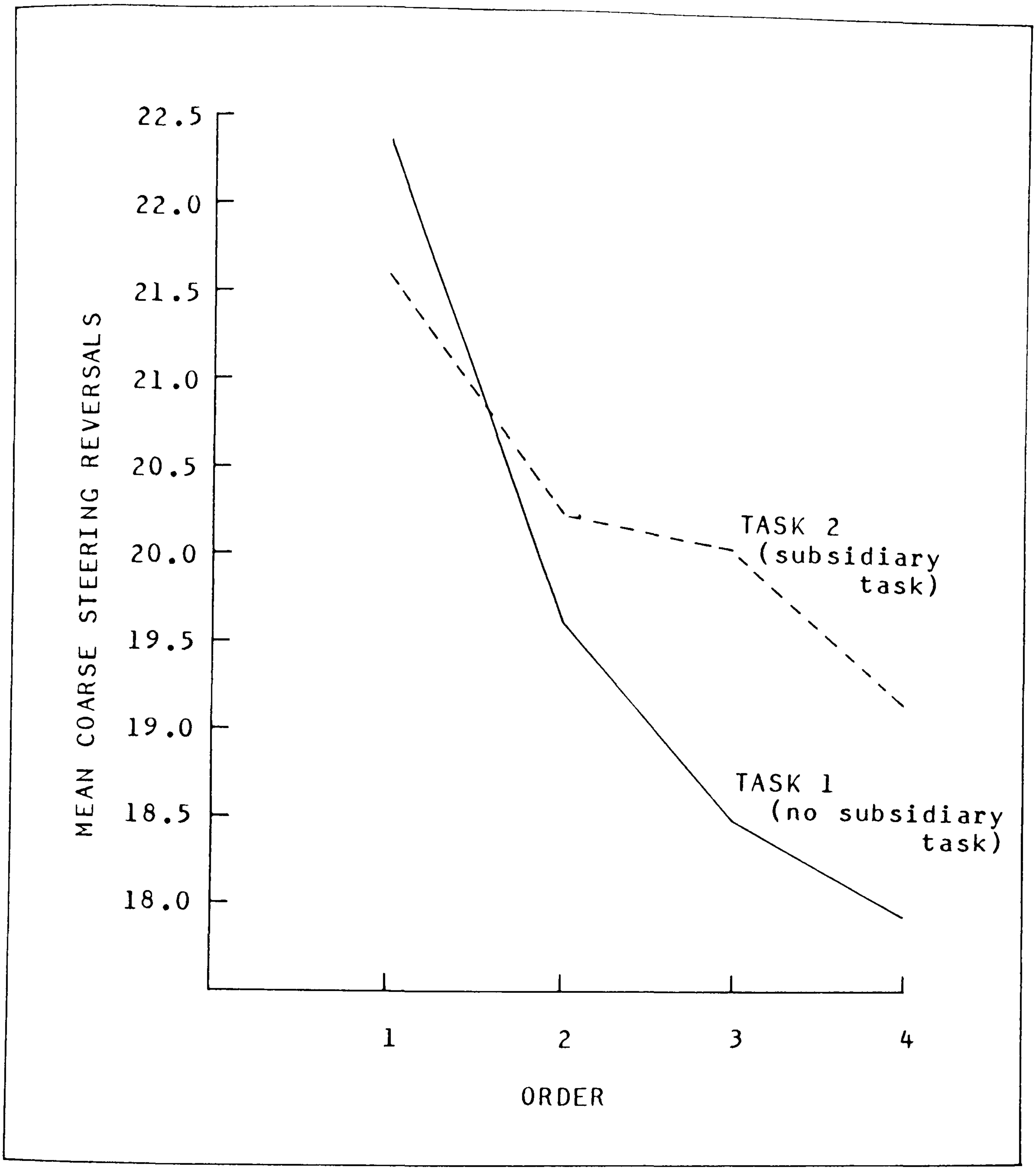


FIGURE 15. Graphic representation of the Order by Task interaction from Analysis of Variance 3. Data are from Test-track 1, dependent variable: Coarse Steer.

The overall main effect of Task was found to be significant, but relatively weaker, est ω^2 = .12, than that of Order. Inspection of the means indicates that the mean number of coarse steering reversals was larger when the subsidiary task was administered than when it was not.

Besides the interaction with Order referred to above, there was also a weak Task by Sex interaction, est ω^2 = .03. When tested individually, only the difference between males' mean coarse steering wheel reversals on Tasks 1 and 2 was found to be statistically significant, $p < .01$, with a higher mean number of reversals occurring in the presence of the subsidiary task.

The presence of the subsidiary task has, therefore, been shown to affect subjects' coarse steering behaviour overall, and with respect to Order and Sex.

4.4.29 ANALYSIS OF VARIANCE 4. DATA ARE FROM TEST-TRACK 2, DEPENDENT VARIABLE: TIME.

The summary table for Analysis of Variance 4 is given in Table 48, where it can be seen that the overall main effects of Sex ($F = 13.4$, d.f. 1 and 90, $p < .01$), Order ($F = 56.2$, d.f. 3 and 270, $p < .01$), Task ($F = 50.0$, d.f. 1 and 90, $p < .01$), and the interaction effect Order by Task ($F = 24.2$, d.f. 3 and 282, $p < .01$) were significant.

Means for the significant effects are shown in Table 49, and those for the Order by Task interaction are plotted graphically in Figure 16.

The overall main effect of Sex was relatively weak, est ω^2 = .11, and it can be seen from the table of means that males (Sex 1) had shorter driving times than females (Sex 2). This agrees with the findings of both the analysis of variance of Test-track 1 data (Analysis of Variance 1), and the previously reported discriminant analyses which indicated that males drove faster than females on the test-track.

TABLE 48. Summary table for Analysis of Variance 4. Data are from Test-track 2, dependent variable: Time.

Source	SS	DF	MS	F	est ω^2
Power	4748.4	4	1187.1	0.56	
Sex	28203.1	1	28203.1	13.41**	.11
Power x Sex	5096.6	4	1274.2	0.61	
Residual	189330.6	90	2103.7	45.98	
Order	12946.4	3	4315.5	56.16**	.36
Power x Order	495.2	12	41.3	0.54	
Sex x Order	190.9	3	63.6	0.83	
Power x Sex x Order	1231.3	12	102.6	1.34	
Residual	20749.2	270	76.8	1.68	
Task	3689.4	1	3689.4	50.01**	.33
Power x Task	121.2	4	30.3	0.41	
Sex x Task	0.0	1	0.0	0.00	
Power x Sex x Task	350.7	4	87.7	1.19	
Residual	6640.1	90	73.8	1.61	
Order x Task	3316.4	3	1105.5	24.16**	.18
Power x Order x Task	817.2	12	68.1	1.49	
Sex x Order x Task	239.2	3	79.7	1.74	
Residual	12902.8	282	45.8		
Totals	291068.8	799			

** Indicates a value of F significant at the 1% level.

The overall main effect of Order was relatively strong, est ω^2 = .36, indicating that approximately 40% of the variance in driving time is accounted for by Order. Inspection of the means shows that driving times decreased steadily over Order, individual comparisons indicating that all pairs of means were significantly different, $p < .01$, except that between Orders 3 and 4 which were non-significant. There was also a fairly strong Order by Task interaction, however, est ω^2 = .18, which indicates that the Order effect was different with respect to the presence or absence of the subsidiary task. Figure 16 shows this quite clearly, there being a significant 'levelling off' effect of Order for Task 2 (presence of the subsidiary task). Individual comparisons of the means showed no significant difference between the means for Tasks 1 and 2 on Orders 1 and 2, but significant differences between task means at levels 3 and 4 of Order, $p < .01$. Within levels of Task, all pairs of means were significantly different at either the one percent or the five percent level except those between Orders 3 and 4 for Task 1, and those between Orders 2 and 3, and Orders 2 and 4 for Task 2.

TABLE 49. Table of means for the significant main effects and interaction from Analysis of Variance 4. Data are from Test-track 2, dependent variable: Time.

Factor	Level			
	Male (1)		Female (2)	
Sex	95.4		107.2	
	1	2	3	4
Order	107.9	101.1	98.8	97.4
	No subsidiary task (1)		Subsidiary task (2)	
Task	99.2		103.4	
Task / Order	No subsidiary task (1)		Subsidiary task (2)	
1	108.1		107.7	
2	100.6		101.6	
3	94.2		103.4	
4	93.7		101.0	

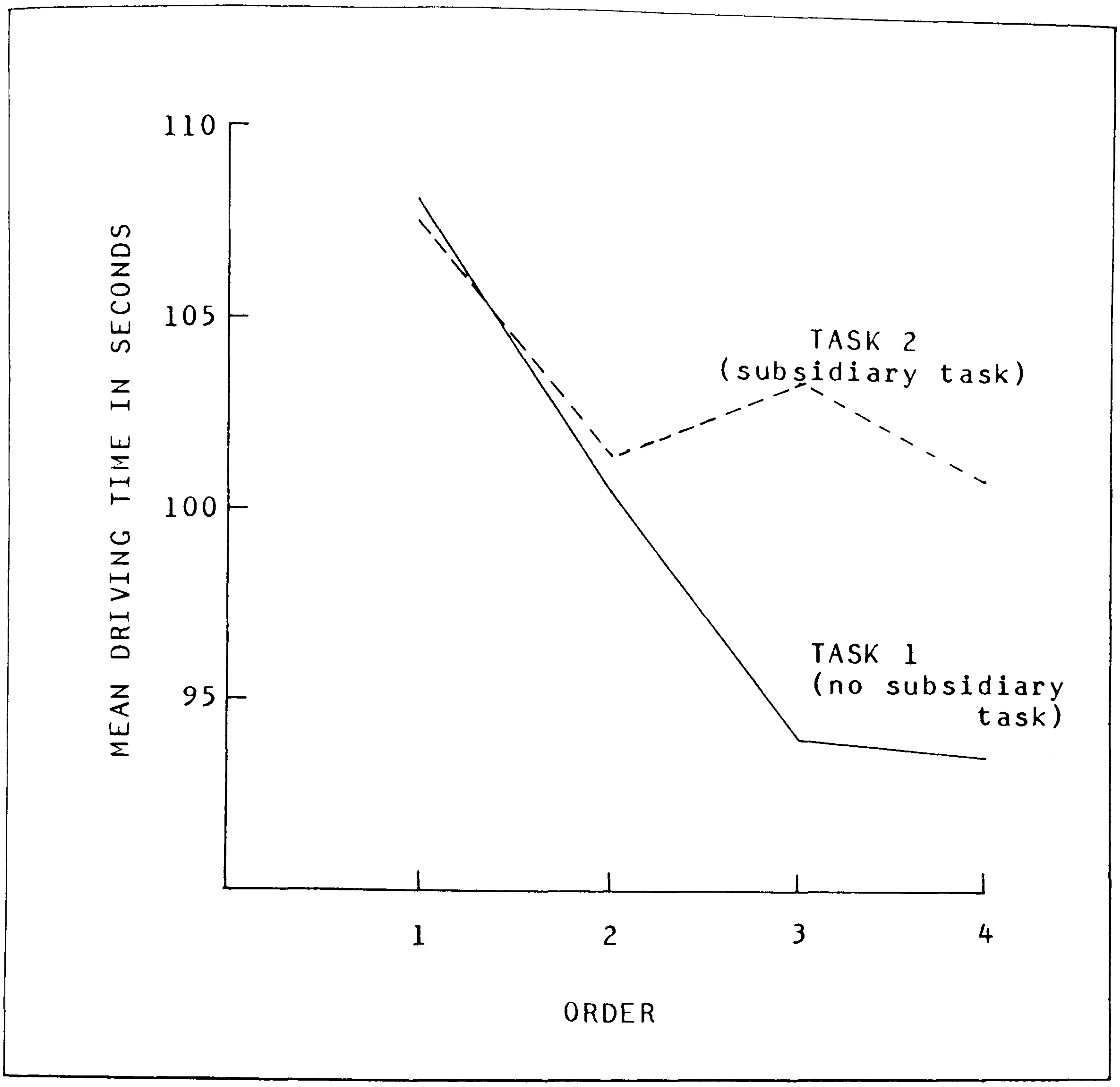


FIGURE 16. Graphic representation of the Order by Task interaction from Analysis of Variance 4. Data are from Test-track 2, dependent variable: Time

The overall main effect of Task itself was also found to be relatively strong, est ω^2 = .33, and inspection of the means shows that driving times were shorter under Task 1 (no subsidiary task) conditions, than under Task 2 (subsidiary task) conditions.

The pattern of differences emerging from Analysis of Variance 4 is almost identical to that seen in Analysis of Variance 1 for test-track1 data. Again, significant effects of subsidiary task on driving times were shown.

4.4.30 ANALYSIS OF VARIANCE 5. DATA ARE FROM TEST-TRACK 2, DEPENDENT VARIABLE: FINE STEER.

The summary table for Analysis of Variance 5 is given in Table 50, where it can be seen that the overall main effects of Order (F = 14.4, d.f. 3 and 270, $p < .01$), Task (F = 155.8, d.f. 1 and 90, $p < .01$), and the Order by Task interaction (F = 3.7, d.f. 3 and 282, $p < .05$), were all significant.

Means for the significant main effects and interaction are given in Table 51, and the means for the Order by Task interaction are presented graphically in Figure 17.

The overall main effect of Order was relatively weak, est ω^2 = .12, and inspection of the means shows a tendency for the number of fine steering reversals to decrease over Order. Individual comparisons show that the difference between all pairs of means are significant at the one percent or five percent level except that between Order 1 and Order 2 which is not significant. There is also a significant but weak, est ω^2 = .03, Order by Task interaction effect, however, and reference to Figure 17 indicates that the effect of Order is different for the two tasks. Individual comparisons between Task means on each level of Order were all significant at the one percent level which confirms the existence of a significant overall Task effect.

TABLE 50. Summary table for Analysis of Variance 5. Data are from Test-track 2, dependent variable: Fine Steer.

Source	SS	DF	MS	F	est ω^2
Power	1734.5	4	433.6	1.51	
Sex	216.3	1	216.3	0.76	
Power x Sex	2448.6	4	612.1	2.14	
Residual	25788.5	90	286.5	16.70	
Order	785.2	3	261.7	14.37**	.12
Power x Order	140.0	12	11.7	0.64	
Sex x Order	27.7	3	9.2	0.51	
Power x Sex x Order	192.5	12	16.0	0.88	
Residual	4917.9	270	18.2	1.06	
Task	3570.1	1	3570.1	155.78**	.61
Power x Task	67.7	4	16.9	0.74	
Sex x Task	6.5	1	6.5	0.28	
Power x Sex x Task	110.4	4	27.6	1.21	
Residual	2062.5	90	22.9	1.34	
Order x Task	191.6	3	63.9	3.72*	.03
Power x Order x Task	66.4	12	5.5	0.32	
Sex x Order x Task	124.0	3	41.3	2.41	
Residual	4839.8	282	17.2		
Totals	47290.1	799			

* Indicates a value of F significant at the 5% level.

** Indicates a value of F significant at the 1% level.

For Task 1 (no subsidiary task), three pairs of Order means were found to be significantly different, those of Orders 1 and 3, 1 and 4, and 3 and 4. For Task 2 (subsidiary task), all pairs of Order means were found to be significantly different, except those of Order 1 and 2. Thus, while the number of fine steering reversals tends to decrease steadily across Order when the subsidiary task (Task 2) was administered, starting and finishing at a relatively high level, mean fine steering reversals remain relatively low under no subsidiary task (Task 1) conditions, rising significantly between Orders 1 and 2, and thereafter decreasing.

TABLE 51. Table of means for the significant main effects and interaction from Analysis of Variance 5. Data are from Test-track 2, dependent variable: Fine steer.

Factor	Level			
	1	2	3	4
Order	34.00	34.38	32.88	31.86
	No subsidiary task (1)		Subsidiary task (2)	
Task	31.17		35.39	
Task	No subsidiary task (1)		Subsidiary task (2)	
Order				
1	31.10		36.93	
2	32.29		36.46	
3	31.24		34.53	
4	30.05		33.66	

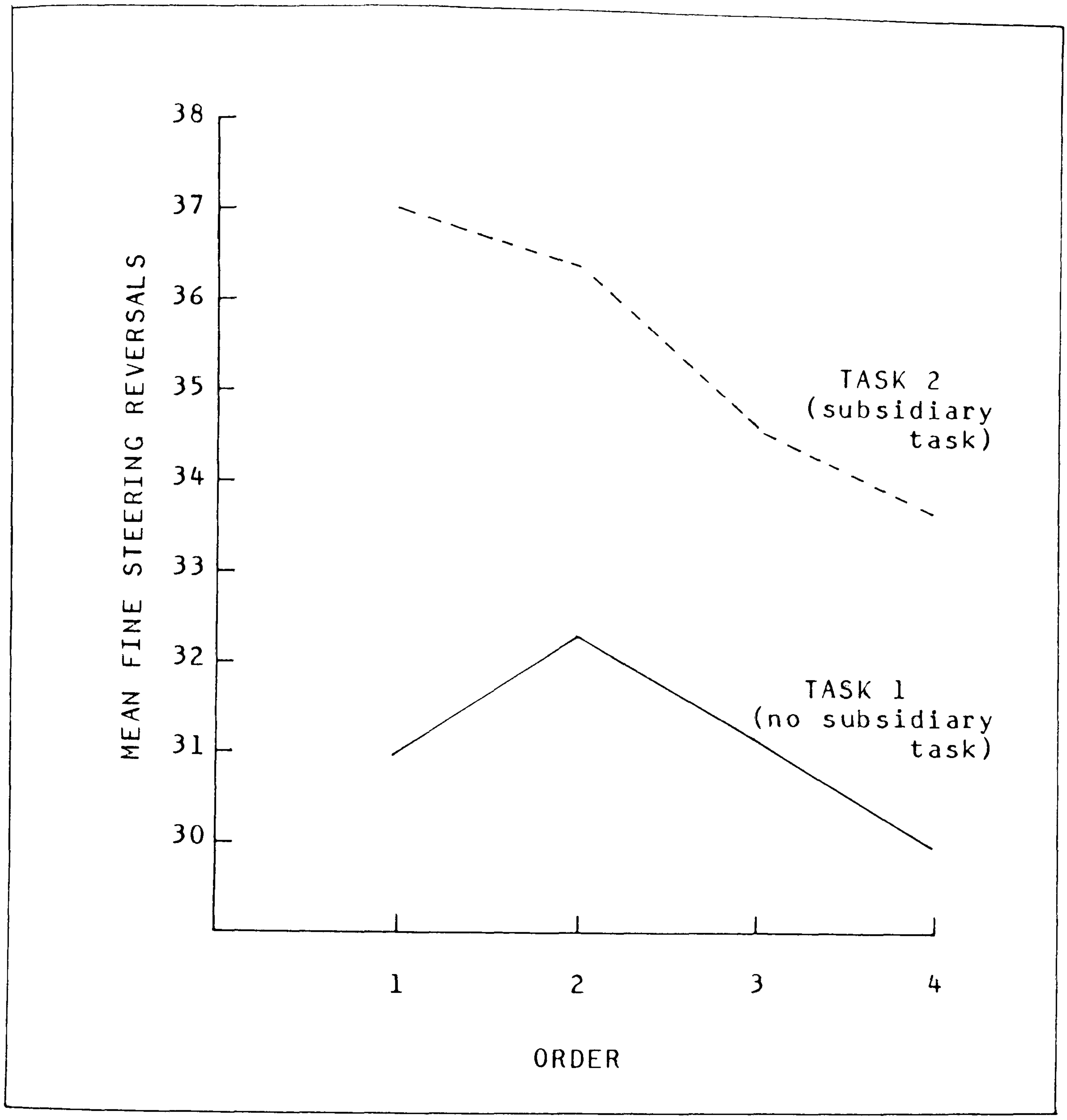


FIGURE 17. Graphic representation of the Task by Order interaction from Analysis of Variance 5. Data are from Test-track 2, dependent variable: Fine Steer.

The significant overall main effect of Task was found to be relatively strong, est $\omega^2 = .61$, inspection of the means indicating that higher numbers of fine steering reversals were associated with the presence of the subsidiary task when considered over all levels of the other factors.

As was the case in Analysis of Variance 2, the presence of the subsidiary task has been shown to affect subjects' fine steering behaviour. The previously seen Order by Sex interaction in the analysis of Test-track 1 data, however, has been replaced by an Order by Task interaction in the present analysis.

4.4.31 ANALYSIS OF VARIANCE 6. DATA ARE FROM TEST-TRACK 2, DEPENDENT VARIABLE: COARSE STEER.

The summary table for Analysis of Variance 6 is given in Table 52, where it can be seen that the main effects of Sex ($F = 4.3$, d.f. 1 and 90, $p < .05$), Order ($F = 7.0$, d.f. 1 and 270, $p < .01$), and Task ($F = 57.2$, d.f. 1 and 90, $p < .01$), were significant, together with a Power by Sex interaction, ($F = 2.6$, d.f. 4 and 90, $p < .05$).

Means for the significant effects are given in Table 53, and the means for the Power by Sex interaction are plotted graphically in Figure 18.

The overall main effect of Sex was weak, est $\omega^2 = .04$, and inspection of the means suggests that males made more coarse steering reversals than females. There was, however, a significant but weak Power by Sex interaction, est $\omega^2 = .06$, and it can be seen from Figure 18 that the number of coarse steering wheel reversals made by males and females differed with respect to the type of power steering in use. Individual comparisons of the means show that only one of the Sex means was significantly different at any level of power steering, that for the Conventional Reaction system (level 4), $p < .01$, and the only differences within Sex were those between the Speed Proportional Feel and Conventional Reaction systems (levels 3 and 4), for both males and females, $p < .05$.

TABLE 52. Summary table for Analysis of Variance 6. Data are from Test-track 2, dependent variable: Coarse Steer.

Source	SS	DF	MS	F	est ω^2
Power	12.8	4	3.2	0.08	
Sex	180.5	1	180.5	4.31*	.04
Power x Sex	431.2	4	107.8	2.57*	.06
Residual	3772.0	90	41.9	7.38	
Order	150.5	3	50.2	7.05**	.06
Power x Order	54.6	12	4.6	0.64	
Sex x Order	11.1	3	3.7	0.52	
Power x Sex x Order	43.8	12	3.6	0.51	
Residual	1920.4	270	7.1	1.25	
Task	300.1	1	300.1	57.22**	.37
Power x Task	9.5	4	2.4	0.45	
Sex x Task	0.1	1	0.1	0.02	
Power x Sex x Task	19.2	4	4.8	0.92	
Residual	472.0	90	5.2	0.92	
Order x Task	19.5	3	6.5	1.14	
Power x Order x Task	68.7	12	5.7	1.00	
Sex x Order x Task	20.9	3	7.0	1.22	
Residual	1601.9	282	5.7		
Totals	9089.0	799			

* Indicates a value of F significant at the 5% level.

** Indicates a value of F significant at the 1% level.

It is interesting that males' highest mean coarse steering reversals, and females' lowest mean coarse steering reversals occurred at the same level of power steering, the Conventional Reaction system, which was probably physically the most demanding system under test-track driving conditions.

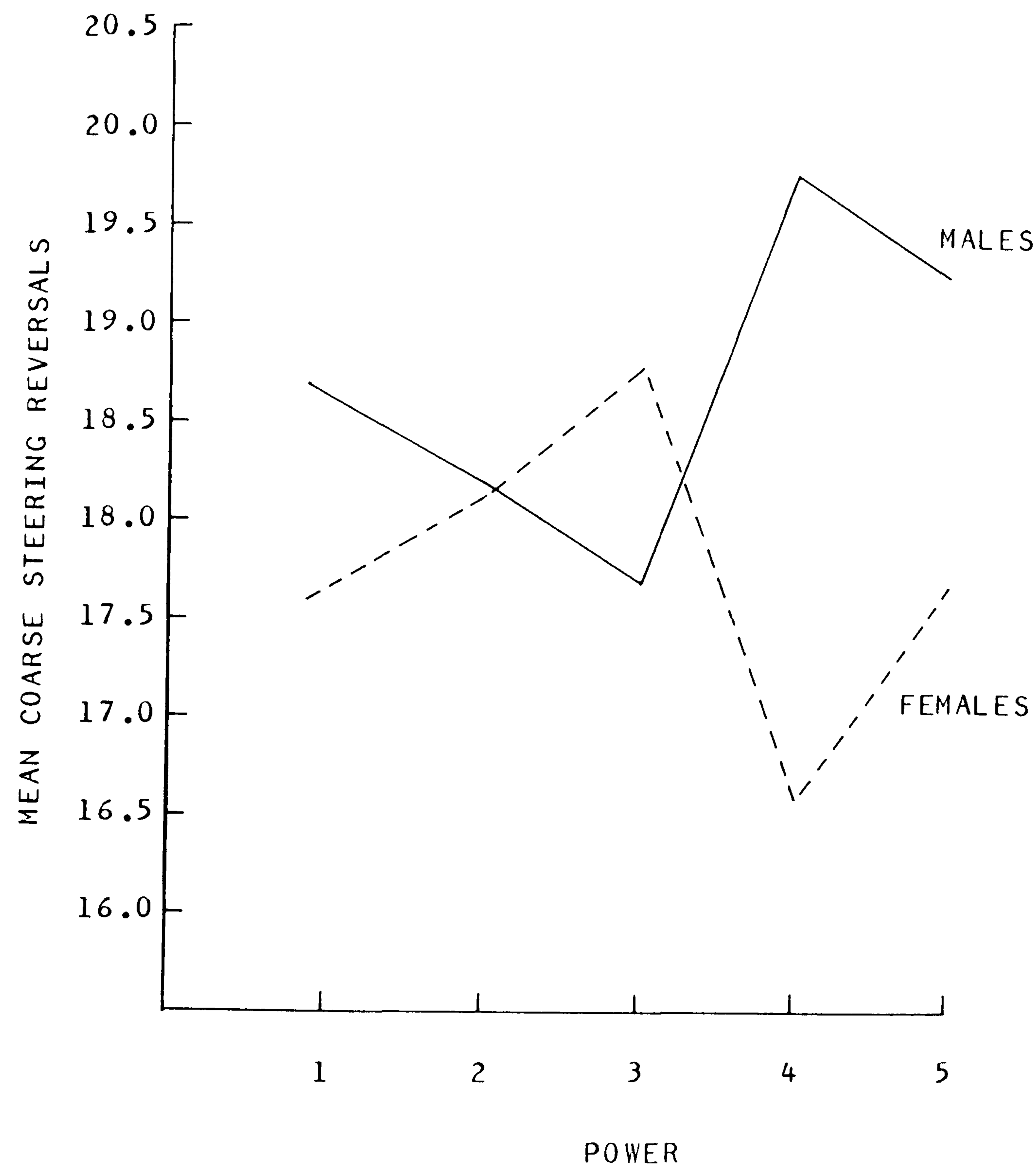
The overall main effect of Order was also relatively weak, est ω^2 = 0.6, inspection of the means indicating a steady reduction in coarse steering reversals over Order. Individual comparisons of means showed that all but the differences between Orders 1 and 2 and Orders 2 and 3 were significant $p < .01$.

The overall main effect of Task was relatively strong, est ω^2 = .37, inspection of the means showing that more coarse steering reversals were made under subsidiary task conditions (Task 2), than under no subsidiary task conditions (Task 1).

Although the results obtained in the present analysis differ somewhat from those of Analysis of Variance 3 (Test-track 1 data), they do confirm the effect of subsidiary task on drivers' coarse steering behaviour.

TABLE 53. Table of means for the significant main effects and interaction from Analysis of Variance 6. Data are from Test-track 2, dependent variable: Coarse steer.

Factor	Level			
	Males (1)		Females (2)	
Sex	18.73		17.78	
	1	2	3	4
Order	18.50	18.83	17.98	17.72
	No subsidiary task (1)		Subsidiary task (2)	
Task	16.64		18.87	
Sex	Males		Females	
Power	(1)		(2)	
1	18.74		17.64	
2	18.18		18.16	
3	17.66		18.81	
4	19.79		16.59	
5	19.30		17.71	



Level
1 Fitted Load Spring Heavy
2 Fitted Load Spring Light
3 Speed Proportional Feel
4 Conventional Reaction
5 Standard Power Steering

FIGURE 18. Graphic representation of the Sex by Power interaction from Analysis of Variance 6. Data are from Test-track 3, dependent variable: Coarse Steer.

It is clear from the results of this and previous analyses of variance that the presence of the subsidiary task has, indeed, affected drivers' primary task performance on the test-track. In general, responding to the subsidiary task caused drivers to drive more slowly and to make greater numbers of fine and coarse steering reversals. It is not possible to interpret subjects' subsidiary task performance directly in terms of the 'spare mental capacity' model, therefore, as the interaction between primary and secondary tasks violates the assumptions described in the Methodology section. However, in the following section, analysis of covariance is employed in order to provide a means of adjusting subsidiary task scores for the demonstrated effect of subsidiary task on drivers' test-track performance.

4.4.32 INTRODUCTION TO THE ANALYSIS OF COVARIANCE OF TEST-TRACK DATA

The analysis of covariance is most commonly used as a means of statistical or 'after the fact' control over one or more extraneous variables which are thought to have affected subjects' performance in an experiment, and which were not controlled for by the experimental design. The rationale employed by the analysis of covariance involves estimating the linear relationship between variate (independent variable) and covariate (the uncontrolled, extraneous variable), and making an adjustment to subjects' scores on the independent variable with respect to that relationship. In effect, the analysis of covariance combines linear regression techniques with the analysis of variance. For a clear and concise account of the rationale and assumptions of the analysis of covariance, the reader is referred to Kirk (1968) chapter 12.

Normally, the analysis of covariance is not employed when the experimental variable of primary interest is known to have an effect on the covariate, since adjusting the dependent variable for the effects of the covariate may, in this case, also remove part of the effect due to the independent variable. In the present example, however, it is still desirable to adjust subsidiary task scores for the demonstrated relationship between primary and secondary task measures even if this reduces the subsidiary task effect, since it is only by this means that subsidiary task scores can properly be considered a measure of 'spare mental capacity'.

A number of analyses of covariance were conducted on the subsidiary task data from Test-track 1 and Test-track 2, therefore, taking as covariates each of the primary task measures Time, Fine Steer and Coarse Steer. This was done simply by specifying the covariate(s) immediately before the analysis of variance directive in the GENSTAT card deck. The analysis of variance design remained exactly as before (see Table 41).

In order that the effects of adjusting the dependent variable for the relationship between variate and covariate can be clearly seen, the GENSTAT program performs an analysis of variance on the unadjusted dependent variable scores prior to each analysis of covariance. In the following sections, therefore, the analyses of covariance performed on the data from both test-track sessions are preceded by an analysis of variance carried out on the unadjusted subsidiary task scores. Comparison of the results of the analysis of variance conducted on the data from one or other of the test-track sessions, and the results of the individual analyses of covariance carried out on the same data indicate the direction and extent of the adjustment made for the relationship between variate and covariate.

A total of eight analyses of covariance were performed on the data from Test-track 1 and Test-track 2, the covariates Time, Fine Steer and Coarse Steer included singly and together for each set of data.

4.4.33 ANALYSIS OF COVARIANCE 1. DATA ARE SUBSIDIARY TASK SCORES FROM TEST-TRACK 1, COVARIATE: TIME.

For comparative purposes, the summary table for the analysis of variance carried out on the unadjusted subsidiary task scores from Test-track 1 is given in Table 54, and the unadjusted means appear in Table 55. It can be seen from Table 54 that the only significant effect found in the analysis of variance of subsidiary task scores from Test-track 1 was a strong Task effect ($F = 322.38$, d.f. 1 and 90, $p < .001$), est $\omega^2 = .75$. Such a task effect was inevitable of course, since the number of subsidiary task responses depends entirely upon the presence or absence of the task itself.

The summary table for the first analysis of covariance carried out on Test-track 1 data is given in Table 56, and the adjusted means appear in Table 57.

TABLE 54. Summary table for the analysis of variance of subsidiary task data from Test-track 1.

Source	SS	DF	MS	F	est ω^2
Power	1960.6	4	490.1	0.88	
Sex	3.9	1	3.9	0.00	
Power x Sex	5507.4	4	1376.8	2.47	
Residual	50083.0	90	556.4	15.84	
Order	129.6	3	43.2	1.20	
Power x Order	515.3	12	42.9	1.19	
Sex x Order	62.2	3	20.7	0.57	
Power x Sex x Order	208.9	12	17.4	0.48	
Residual	9696.3	270	35.9	1.02	
Task	179400.5	1	179400.5	322.38**	.75
Power x Task	1960.6	4	490.1	0.88	
Sex x Task	3.9	1	3.9	0.00	
Power x Sex x Task	5507.4	4	1376.8	2.47	
Residual	50083.0	90	556.4	15.84	
Order x Task	129.6	3	43.2	1.23	
Power x Order x Task	515.3	12	42.9	1.22	
Sex x Order x Task	62.2	3	20.7	0.59	
Residual	9905.2	282	35.1		
Totals	315735.5	799			

** Indicates a value of F significant at the 1% level.

TABLE 55. Table of unadjusted means from the analysis of variance of subsidiary task data from Test-track 1. N.B. Only the means associated with the main effect of Task were found to be significantly different. The other means in this table are provided for comparison purposes with those associated with significant effects found in subsequent analyses of covariance.

Factor	Level			
Task	No subsidiary task (1)		Subsidiary task (2)	
	0.00		29.95	
Order	1	2	3	4
	14.34	14.92	15.31	15.33
Task	No subsidiary task (1)		Subsidiary task (2)	
Power				
1	0.00		32.80	
2	0.00		27.72	
3	0.00		33.30	
4	0.00		25.06	
5	0.00		30.86	

From Table 56 it can be seen that, when the subsidiary task scores are adjusted for the covariate Time, a significant Order effect emerges, ($F = 19.2$, d.f. 3 and 269, $p < .01$) in addition to the powerful Task effect already noted, ($F = 282.28$, d.f. 1 and 89, $p < .001$). Comparison of Tables 54 and 56 indicates that by adjusting subsidiary task scores for the covariate Time, the size of the Task effect is reduced, and is somewhat less powerful, est $\omega^2 = .68$. This reflects the fact that the presence of the subsidiary task is known to affect drivers' speed on the test-track.

TABLE 56. Summary table for Analysis of Covariance 1. Data are subsidiary task scores from Test-track 1, covariate: Time.

Source	SS	DF	MS	F	est ω^2
Power	1504.2	4	376.0	0.80	
Sex	819.7	1	819.7	1.75	
Power x Sex	3112.9	4	778.2	1.66	
Covariates	8542.2	1	8542.2	18.30	
Residual	41540.7	89	466.7	13.34	
Order	1671.2	3	577.0	19.23**	.13
Power x Order	480.0	12	40.0	1.38	
Sex x Order	75.3	3	25.1	0.86	
Power x Sex x Order	98.8	12	8.2	0.28	
Covariates	1906.6	1	1906.6	65.84	
Residual	7789.6	269	28.9	0.82	
Task	122270.6	1	122270.6	282.28**	.68
Power x Task	3231.1	4	807.7	1.86	
Sex x Task	93.5	1	93.5	0.21	
Power x Sex x Task	4163.2	4	1040.8	2.40	
Covariates	11532.5	1	11532.5	26.62	
Residual	38550.5	89	433.1	12.38	
Order x Task	23.0	3	7.6	0.21	
Power x Order x Task	510.9	12	42.5	1.21	
Sex x Order x Task	70.9	3	23.6	0.67	
Covariates	74.4	1	74.4	2.12	
Residual	9830.8	281	34.9		
Totals	257893.3	799			

** Indicates a value of F significant at the 1% level.

TABLE 57. Table of adjusted means for the significant main effects from Analysis of Covariance 1. Data are subsidiary task scores from Test-track 1, covariate: Time.

Factor	Level			
	1	2	3	4
Order	11.28	15.01	16.38	17.22
	No subsidiary task (1)		Subsidiary task (2)	
Task	1.56		28.37	

The effect of adjusting subsidiary task scores for the covariate is also to make the adjusted means under the subsidiary task condition (Task 1) non-zero, as shown in Table 57.

Although the significant Order effect found after adjustment for the covariate was relatively weak, est. $\omega^2 = .13$, it can be seen from Table 57 that there was a tendency for the number of subsidiary task responses to increase over Order. Individual comparisons of the Order means produced significant differences at the 1% level for all pairs except that between Orders 3 and 4 which was non-significant.

The results of this first analysis of covariance indicate that when the previously noted relationship between drivers' speed and the presence of the subsidiary task is removed, a tendency for drivers to respond more frequently to the subsidiary task as the test-track session progresses becomes apparent.

4.4.34 ANALYSIS OF COVARIANCE 2. DATA ARE SUBSIDIARY TASK SCORES FROM TEST-TRACK 1, COVARIATE: FINE STEER.

The summary table for Analysis of Covariance 2 is given in Table 58, where it can be seen that the overall main effect of Order ($F = 7.0$, d.f. 3 and 269, $p < .01$), and Task ($F = 108.0$, d.f. 1 and 89, $p < .01$) were both significant. The adjusted means associated with these significant effects are given in Table 59.

Comparison of Tables 58 and 54 indicates that the effect of adjusting subsidiary task scores for the covariate Fine Steer has been to reduce the strength of the expected Task effect from est. $\omega^2 = .75$ to est. $\omega^2 = .42$. This simply reflects the fact that the presence of the subsidiary task was previously found to affect subjects' fine steering frequency. A similar reduction in the strength of the Task effect was noted in the previous analyses in which Time was used as the covariate.

Inspection of Table 59 indicates that the significant but weak Order effect, est. $\omega^2 = .05$, was one of an increasing number of subsidiary task responses over Order. Individual comparisons between pairs of Order means were significant at the 1% or 5% levels except for those between Orders 2 and 3 and Orders 3 and 4, which were not significant.

The results of Analysis of Covariance 2 are similar to those of Analysis of Covariance 1, in that adjustment for the covariate resulted in a weakened Task effect, and a significant but relatively weak Order effect. The latter again suggests that drivers responded more frequently to the subsidiary task as the test-track session proceeded.

TABLE 58. Summary table for Analysis of Covariance 2. Data are subsidiary task scores from Test-track 1, covariate: Fine Steer.

Source	SS	DF	MS	F	est ω^2
Power	1898.0	4	474.5	0.90	
Sex	4.0	1	4.0	0.00	
Power x Sex	4138.0	4	1034.5	1.97	
Covariates	3367.9	1	3367.9	6.41	
Residual	46715.0	89	524.8	15.08	
Order	703.9	3	234.6	7.00**	.05
Power x Order	470.5	12	39.2	1.17	
Sex x Order	15.9	3	5.3	0.15	
Power x Sex x Order	231.5	12	19.2	0.57	
Covariates	682.4	1	682.4	20.36	
Residual	9013.8	269	33.5	0.96	
Task	42311.1	1	42311.1	108.00**	.48
Power x Task	2953.4	4	738.3	1.88	
Sex x Task	24.8	1	24.8	0.06	
Power x Sex x Task	3705.5	4	926.4	2.36	
Covariates	15218.3	1	15218.3	38.84	
Residual	34864.6	89	391.7	11.26	
Order x Task	132.1	3	44.0	1.26	
Power x Order x Task	526.4	12	43.8	1.26	
Sex x Order x Task	57.3	3	19.1	0.54	
Covariates	129.6	1	129.6	3.72	
Residual	9775.5	281	34.7		
Totals	10621.1	799			

** Indicates a value of F significant at the 1% level.

TABLE 59. Table of adjusted means for the significant main effects from Analysis of Covariance 2. Data are subsidiary task scores from Test-track 1, covariate: Time.

Factor	Level			
	1	2	3	4
Order	12.85	14.90	15.77	16.38
	No subsidiary task (1)		Subsidiary task (2)	
Task	4.51		25.44	

4.4.35 ANALYSIS OF COVARIANCE 3. DATA ARE SUBSIDIARY TASK SCORES FROM TEST-TRACK 1, COVARIATE: COARSE STEER.

The summary table for Analysis of Covariance 3 is given in Table 60, where it can be seen that only the overall main effect of Task was significant, ($F = 257$, d.f. 1 and 89, $p < .01$).

Comparison of Table 60 and 54 indicates that the effect of adjusting subsidiary task scores for the covariate Coarse steer was to reduce the strength of the expected task effect from est.$\omega^2 = .75$ to est.$\omega^2 = .70$. The adjusted task means were .77 for Task 1 (no subsidiary task) and 29.18 for Task 2 (subsidiary task). Again, it is interesting to note that the subsidiary task scores under Task 1 (no task) conditions become non-zero, reflecting the previously demonstrated relationship between the presence of the subsidiary task and drivers' coarse steering frequency.

TABLE 60. Summary table for Analysis of Covariance 3. Data are subsidiary task scores from Test-track 1, covariate: Coarse Steer.

Source	SS	DF	MS	F	est ω^2
Power	2020.7	4	505.1	0.92	
Sex	21.7	1	21.7	0.04	
Power x Sex	4744.7	4	1186.1	2.16	
Covariates	1355.1	1	1355.1	2.47	
Residual	48727.8	89	547.5	15.53	
Order	212.6	3	70.8	1.98	
Power x Order	511.5	12	42.6	1.19	
Sex x Order	50.9	3	17.0	0.47	
Power x Sex x Order	194.7	12	16.2	0.45	
Covariates	82.9	1	82.9	2.32	
Residual	9613.3	269	35.7	1.01	
Task	137024.8	1	137024.8	257.24**	.70
Power x Task	2139.4	4	534.8	1.00	
Sex x Task	180.0	1	180.0	0.33	
Power x Sex x Task	4650.4	4	1162.6	2.18	
Covariates	2676.3	1	2676.3	5.02	
Residual	47406.7	89	532.6	15.11	
Order x Task	111.4	3	37.1	1.05	
Power x Order x Task	516.3	12	43.0	1.22	
Sex x Order x Task	61.0	3	20.3	0.57	
Covariates	1.2	1	1.2	0.03	
Residual	9903.9	281	35.2		
Totals	272208.2	799			

** Indicates a value of F significant at the 1% level.

4.4.36 ANALYSIS OF COVARIANCE 4. DATA ARE SUBSIDIARY TASK SCORES FROM TEST-TRACK 1, COVARIATES: TIME, FINE STEER AND COARSE STEER.

In the last of the series of analyses of covariance conducted on the subsidiary task data from Test-track 1, all three of the primary task measures, Time, Fine Steer and Coarse Steer were included as covariates.

The summary table for Analysis of Covariance 4 is given in Table 61, where it can be seen that the overall main effects of Order ($F = 18.0$, d.f. 3 and 267, $p < .01$), Task ($F = 117.7$, d.f. 1 and 87, $p < .01$), and the Power by Task interaction ($F = 2.57$, d.f. 4 and 87, $p < .05$), were all significant.

Adjusted means for the significant effects from Analysis of Covariance 4 are given in Table 62, and the means associated with the significant Power by Task interaction are plotted graphically in Figure 19.

A comparison of Tables 61 and 54 indicates that the strength of the expected Task effect has been reduced by the adjustment made for the covariates from est.$\omega^2 = .75$ to est.$\omega^2 = .43$. This tendency was noted in the results of previous analyses of covariance, and can be attributed to the relationship demonstrated earlier between the presence of the subsidiary task and the primary task variables.

It can be seen from the adjusted means given in Table 62 that the relatively weak Order effect, est.$\omega^2 = .12$, was one of increasing numbers of subsidiary task responses over Order. Individual comparisons between all pairs of means were significant at the 1% or 5% levels except that between Orders 3 and 4, which was not significant.

TABLE 61. Summary table for Analysis of Covariance 4. Data are subsidiary task scores from Test-track 1, covariates: Time, Fine Steer, Coarse Steer.

Source	SS	DF	MS	F	est ω^2
Power	1221.4	4	305.3	0.67	
Sex	885.4	1	885.4	1.96	
Power x Sex	2634.4	4	658.6	1.45	
Covariates	10770.7	3	3590.2	7.94	
Residual	39312.2	87	451.8	12.96	
Order	1547.9	3	515.9	18.02**	.12
Power x Order	454.3	12	37.8	1.32	
Sex x Order	57.4	3	19.1	0.66	
Power x Sex x Order	108.9	12	9.0	0.31	
Covariates	2054.6	3	684.8	23.93	
Residual	7641.6	267	28.6	0.82	
Task	42113.3	1	42113.3	117.73**	.42
Power x Task	3675.9	4	918.9	2.56*	.02
Sex x Task	20.8	1	20.8	0.05	
Power x Sex x Task	3398.6	4	849.6	2.37	
Covariates	18964.0	3	6321.3	17.67	
Residual	31118.9	87	357.6	10.26	
Order x Task	48.4	3	16.1	0.46	
Power x Order x Task	517.6	12	43.1	1.23	
Sex x Order x Task	66.3	3	22.1	0.63	
Covariates	181.8	3	60.6	1.73	
Residual	9723.4	279	34.8		
Totals	176518.5	799			

* Indicates a value of F significant at the 5% level.

** Indicates a value of F significant at the 1% level.

TABLE 62. Table of adjusted means for the significant main effects and interaction from Analysis of Covariance 4. Data are subsidiary task scores from Test-track 1, covariates: Time, Fine Steer and Coarse Steer.

Factor	Level			
	1	2	3	4
Order	11.23	15.00	16.39	17.28
	No subsidiary task (1)		Subsidiary task (2)	
Task	4.49		25.46	
	No subsidiary task		Subsidiary task	
Task	(1)		(2)	
Power				
1	2.30		30.06	
2	7.02		22.24	
3	4.55		28.04	
4	3.95		21.83	
5	4.62		25.13	

The Power by Task interaction, although significant at the 5% level, was very weak, est. $\omega^2 = .02$. Individual comparisons between all pairs of interaction means revealed no significant differences between Task 1 means (no subsidiary task), significant differences between all Task 1 and Task 2 (subsidiary task) means, $p < .01$, and significant differences between Task 2 (subsidiary task) means for power steering groups 1 and 2, the Load Spring Heavy and Load Spring Light groups, and groups 1 and 4, the Load Spring Heavy and Conventional Reaction groups, $p < .05$.

The existence of a Power by Task interaction effect associated with the subsidiary task data from Test-track 1 is something of an anomaly, however, since subjects had been allocated to a power steering group, but were all driving with the standard

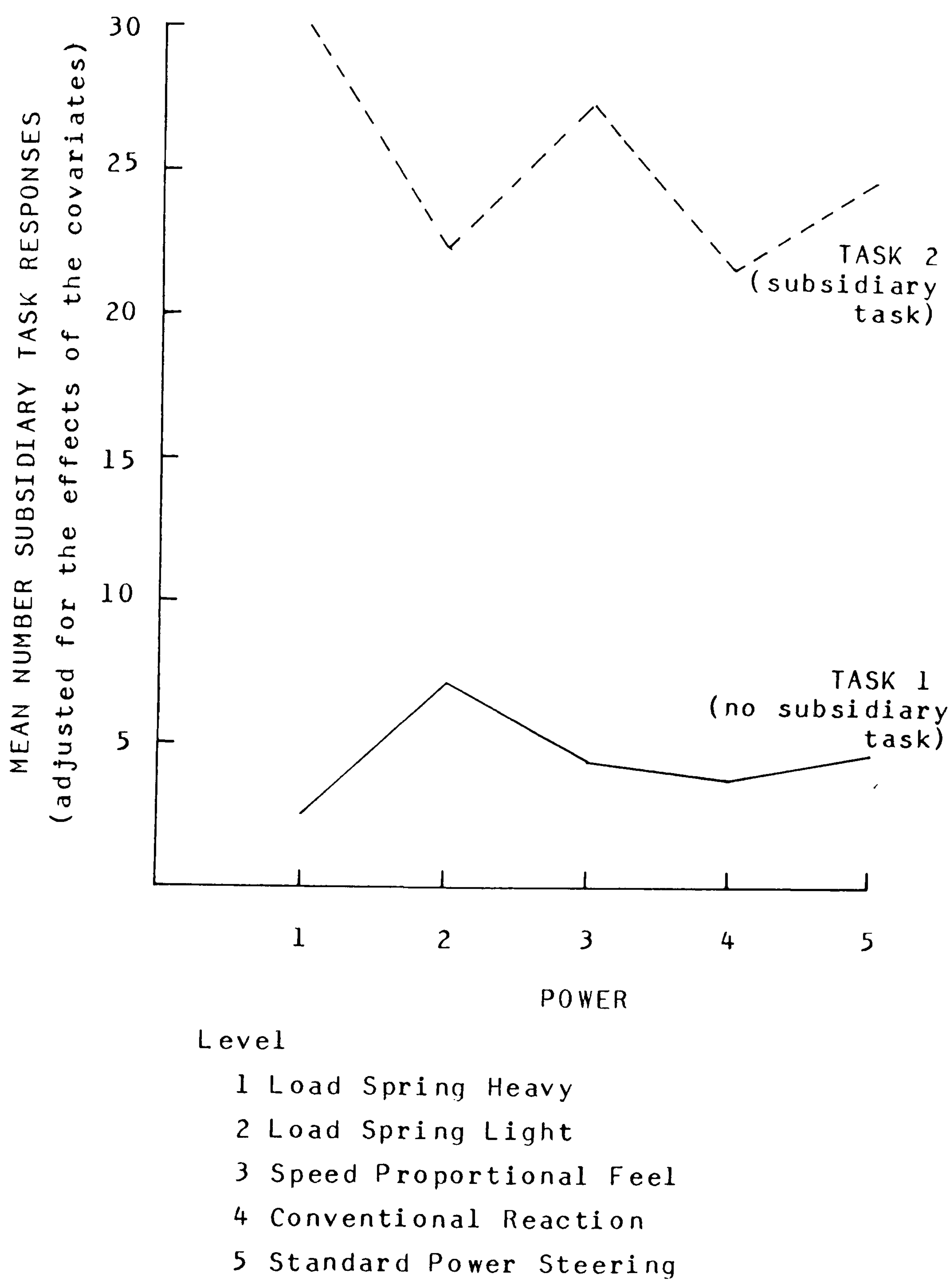


FIGURE 19. Graphic representation of the Power by Task interaction from Analysis of Covariance 4. Data are from Test-track 1, dependent variable: Subsidiary task responses, covariates: Time, Fine Steer and Coarse Steer.

power steering system during this test-track session. Assuming that this is not a purely chance result, it would seem that subjects who were to drive with the Load Spring Heavy system in the second test-track session, made significantly more subsidiary task responses on the first test-track session than subjects who were to drive with the Load Spring Light and Conventional Reaction systems. In short, it would seem that, when adjustments for the three covariates of Time, Fine Steer and Coarse Steer are made, the number of subsidiary task responses was not found to be the same for all groups of subjects. It should be remembered that the effect was extremely weak, however, in that approximately 2% of the variance in subsidiary task responses was accounted for by the Power by Task interaction. The implications of this finding will be further discussed in relation to the results of Analysis of Covariance 6, later in this section.

In summarizing the results of the analyses of covariance carried out on subsidiary task data from Test-track 1, the following should be noted:

(i) Each analysis produced the expected Task effect.

(ii) A fairly weak Order effect was seen when Time and Fine Steer were taken as covariates.

(iii) A very weak Power by Task interaction was seen when Time, Fine Steer and Coarse Steer were taken as covariates.

4.4.37 ANALYSIS OF COVARIANCE 5. DATA ARE SUBSIDIARY TASK SCORES FROM TEST-TRACK 2, COVARIATE: TIME.

For comparative purposes, the summary table for the analysis of variance carried out on the unadjusted subsidiary task scores from Test-track 2 is given in Table 63, and the unadjusted means appear in Table 64.

From Table 63 it can be seen that a number of significant effects were found in the analysis of variance of subsidiary task scores from Test-track 2, namely, an overall main effect of Order ($F = 4.38$, d.f. 3 and 270, $p < .01$), and Task ($F = 410.76$, d.f. 1 and 90, $p < .01$), and interaction effects of Power by Sex ($F = 2.68$, d.f. 4 and 90, $p < .05$) Order by Task ($F = 4.40$, d.f.

3 and 282, $p < .01$) and Power by Sex by Task ($F = 2.68$, d.f. 4 and 90, $p < .05$). From the estimated values of ω^2 given in Table 63, it can be seen that all the significant effects, with the exception of the inevitable Task effect, were extremely weak.

The summary table for the first analysis of covariance carried out on Test-track 2 data is given in Table 65, and the adjusted means are shown in Table 66.

A comparison of Tables 63 and 65 shows that when subsidiary task scores are adjusted for the effects of the covariate Time, the Order effect is strengthened, the Task effect weakened and two of the three interactions seen in the analysis of variance become non-significant. Reference to Table 66 indicates that the relatively weak Order effect was in the expected direction, with greater numbers of subsidiary task responses being made as the test-track session progressed. The presence of a significant Order by Task interaction indicates that this effect was different with respect to the two levels of the Task variable, however, and the interaction is graphed in Figure 20. Individual comparisons carried out on the interaction means revealed no significant differences between Task 1 (no subsidiary task) means, significant differences between Task 1 and Task 2 (subsidiary task) means at each level of Order, $p < .01$, and significant differences between Task 2 means for all levels of Order except those of Order 3 and 4, $p < .05$.

TABLE 63. Summary table for the analysis of variance of subsidiary task data from Test-track 2.

Source	SS	DF	MS	F	estω^2
Power	1737.2	4	434.3	0.90	
Sex	22.4	1	22.4	0.04	
Power x Sex	5172.0	4	1293.0	2.68*	.06
Residual	43412.1	90	482.3	29.43	
Order	216.3	3	72.1	4.38**	.03
Power x Order	324.8	12	27.0	1.64	
Sex x Order	43.4	3	14.4	0.87	
Power x Sex x Order	172.1	12	14.3	0.87	
Residual	4449.2	270	16.4	1.00	
Task	198135.1	1	198135.1	410.76**	.79
Power x Task	1737.2	4	434.3	0.90	
Sex x Task	22.4	1	22.4	0.04	
Power x Sex x Task	5172.0	4	1293.0	2.68*	.01
Residual	43412.1	90	482.3	29.43	
Order x Task	216.3	3	72.1	4.40**	.03
Power x Order x Task	324.8	12	27.0	1.65	
Sex x Order x Task	43.4	3	14.4	0.88	
Residual	4621.3	282	16.3		
Totals	309234.8	799			

* Indicates a value of F significant at the 5% level.

** Indicates a value of F significant at the 1% level.

TABLE 64. Table of unadjusted means from the analysis of variance of subsidiary task data from Test-track 2.

Factor	Level			
	1	2	3	4
Order	14.96	15.58	16.25	16.17
	No subsidiary task (1)		Subsidiary task (2)	
Task	0.00		31.48	
Sex	Males (1)		Females (2)	
Power				
1	13.98		19.69	
2	16.14		15.22	
3	14.31		19.52	
4	16.19		9.66	
5	18.91		13.75	
Task	No subsidiary task (1)		Subsidiary task (2)	
Order				
1	0.00		29.91	
2	0.00		31.16	
3	0.00		32.49	
4	0.00		32.34	
Sex	Males (1)		Females (2)	
Task	No subsidiary task (1)	Subsidiary task (2)	No subsidiary task (1)	Subsidiary task (2)
Power				
1	0.00	27.95	0.00	39.38
2	0.00	32.27	0.00	30.45
3	0.00	28.62	0.00	39.05
4	0.00	32.37	0.00	19.32
5	0.00	37.82	0.00	27.50

TABLE 65. Summary table for Analysis of Covariance 5. Data are subsidiary task scores from Test-track 2, covariate: Time.

Source	SS	DF	MS	F	est ω^2
Power	1612.6	4	403.1	0.98	
Sex	1183.2	1	1183.2	2.88	
Power x Sex	3548.2	4	887.0	2.16	
Covariates	6932.1	1	6932.1	16.91	
Residual	36480.0	89	409.8	24.94	
Order	488.3	3	162.7	10.53**	.08
Power x Order	304.4	12	25.3	1.64	
Sex x Order	45.7	3	15.2	0.98	
Power x Sex x Order	190.4	12	15.8	1.02	
Covariates	293.6	1	293.6	19.00	
Residual	4155.5	269	15.4	0.94	
Task	91680.6	1	91680.6	231.68**	.65
Power x Task	1972.7	4	493.1	1.24	
Sex x Task	24.7	1	24.7	0.06	
Power x Sex x Task	2859.4	4	714.8	1.80	
Covariates	8193.4	1	8193.4	20.70	
Residual	25218.6	89	395.7	24.08	
Order x Task	201.1	3	67.0	4.08**	.06
Power x Order x Task	329.0	12	27.4	1.66	
Sex x Order x Task	39.5	3	13.1	0.80	
Covariates	4.3	1	4.3	0.26	
Residual	4617.0	281	16.4		
Totals	200375.3	799			

** Indicates a value of F significant at the 1% level.

TABLE 66. Table of adjusted means from Analysis of Covariance 5. Data are subsidiary task scores from Test-track 2, covariate: Time.

Factor	Level			
	1	2	3	4
Order	14.17	15.60	16.54	16.63
	No subsidiary task (1)		Subsidiary task (2)	
Task	2.39		29.09	
	No subsidiary task (1)		Subsidiary task (2)	
Task Order				
1	1.65		26.70	
2	2.44		28.76	
3	2.64		30.45	
4	2.82		30.45	

The expected Task effect was found to be somewhat weaker when adjustment was made for the covariate, the estimated value of ω^2 being reduced from est. ω^2 = .79 to est. ω^2 = .65, again reflecting the previously demonstrated effect of the subsidiary task on drivers' test-track speeds.

The results of Analysis of Covariance 5 indicate that when subsidiary task scores are adjusted for the covariate Time, there is a tendency for subjects to respond more frequently to the subsidiary task during the course of the second test-track session. There was no significant increase in subsidiary task responses between Orders 3 and 4, however, possibly indicating that a ceiling had been reached in subjects' ability to respond to the subsidiary task.

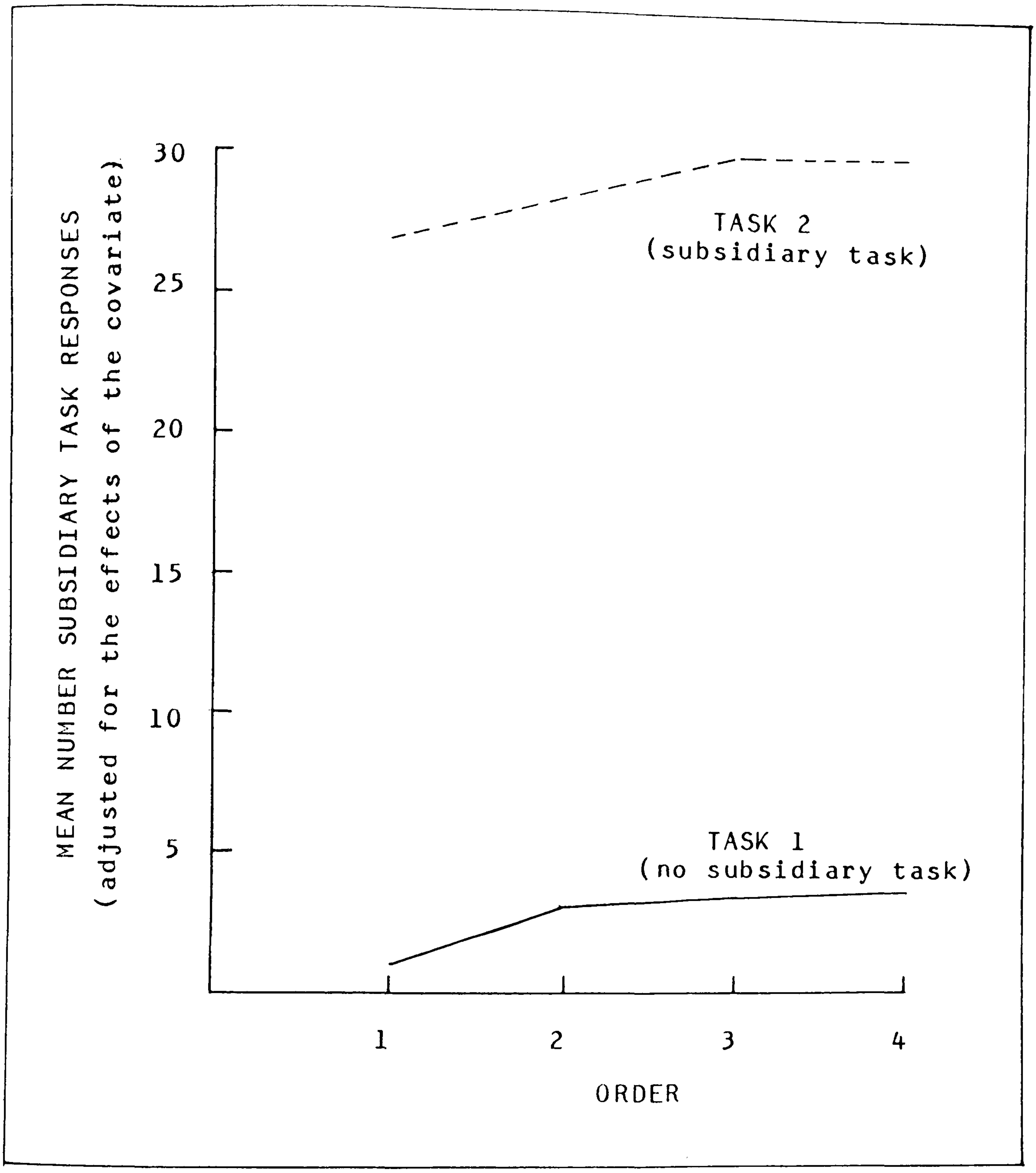


FIGURE 20. Graphic representation of the Order by Task interaction from Analysis of Covariance 5. Data are from Test-track 2, dependent variable: Subsidiary task responses, covariate: Time.

4.4.38 ANALYSIS OF COVARIANCE 6. DATA ARE SUBSIDIARY TASK SCORES FROM TEST-TRACK 2, COVARIATE: FINE STEER.

The summary table for Analysis of Covariance 6 is given in Table 67, where it can be seen that the overall main effects of Order ($F = 8.9$, d.f.3 and 269, $p < .01$), and Task ($F = 98.2$, d.f. 1 and 89, $p < .01$), the Order by Task interaction ($F = 4.35$, d.f. 3 and 281, $p < .01$) and the Power by Sex by Task interaction ($F = 3.01$, d.f. 4 and 89, $p < .05$), were all significant.

Adjusted means for the significant effects from Analysis of Covariance 6 are given in Table 68 where it can be seen that the fairly weak Order effect, est. $\omega^2 = .07$, was in the expected direction with increasing numbers of subsidiary task responses over the course of the test-track session. Individual comparisons were significant at the one percent level for all pairs of Order means except those between Orders 1 and 2, and between Orders 3 and 4 which were non-significant. The significant Order by Task interaction was similar to that seen in the previous analysis of covariance (see Figure 20), in that there were no significant differences between Task 1 (no subsidiary task) means over Order, and the differences between Task 2 (subsidiary task) means following the same pattern as that shown for the main effect of Order.

The significant Task effect was to be expected as before, and its reduced strength, est. $\omega^2 = .42$, after adjustment for the covariate is again attributed to the previously found effect of subsidiary task on drivers' fine steering frequency.

TABLE 67. Summary table for Analysis of Covariance 6. Data are subsidiary task scores from Test-track 2, covariate: Fine Steer.

Source	SS	DF	MS	F	est ω^2
Power	1462.6	4	365.6	0.78	
Sex	0.2	1	0.2	0.00	
Power x Sex	3533.6	4	883.4	1.90	
Covariates	2184.1	1	2184.1	4.71	
Residual	41228.0	89	463.2	28.17	
Order	403.4	3	134.4	8.90**	.07
Power x Order	300.4	12	25.0	1.65	
Sex x Order	31.1	3	10.3	0.68	
Power x Sex x Order	180.5	12	15.0	0.99	
Covariates	385.8	1	385.8	25.54	
Residual	4063.3	269	15.1	0.91	
Task	38702.8	1	38702.8	98.16**	.42
Power x Task	1464.0	4	366.0	0.92	
Sex x Task	96.7	1	96.7	0.24	
Power x Sex x Task	4759.2	4	1189.8	3.01*	.04
Covariates	8321.2	1	8321.2	21.10	
Residual	35090.9	89	394.2	23.98	
Order x Task	214.5	3	71.5	4.35**	.03
Power x Order x Task	324.4	12	27.0	1.64	
Sex x Order x Task	44.3	3	14.7	0.89	
Covariates	1.2	1	1.2	0.07	
Residual	4620.1	281	16.4		
Totals	147413.2	799			

* Indicates a value of F significant at the 5% level.

** Indicates a value of F significant at the 1% level.

TABLE 68. Table of adjusted means from Analysis of Covariance 6. Data are subsidiary task responses from Test-track 2, covariate: Fine Steer.

Factor	Level			
	1	2	3	4
Order	14.75	15.27	16.36	16.57
	No subsidiary task (1)		Subsidiary task (2)	
Task	4.24		27.23	
Sex	Males (1)		Females (2)	
Task	No subsidiary task (1)	Subsidiary task (2)	No subsidiary task (1)	Subsidiary task (2)
Power				
1	3.67	25.05	4.26	36.05
2	5.75	26.08	4.15	26.67
3	4.20	25.54	4.98	32.53
4	3.32	28.06	4.71	17.35
5	2.61	33.26	4.78	21.73
Task	No subsidiary task (1)		Subsidiary task (2)	
Order				
1	4.05		25.45	
2	3.94		26.61	
3	4.35		28.37	
4	4.64		28.50	

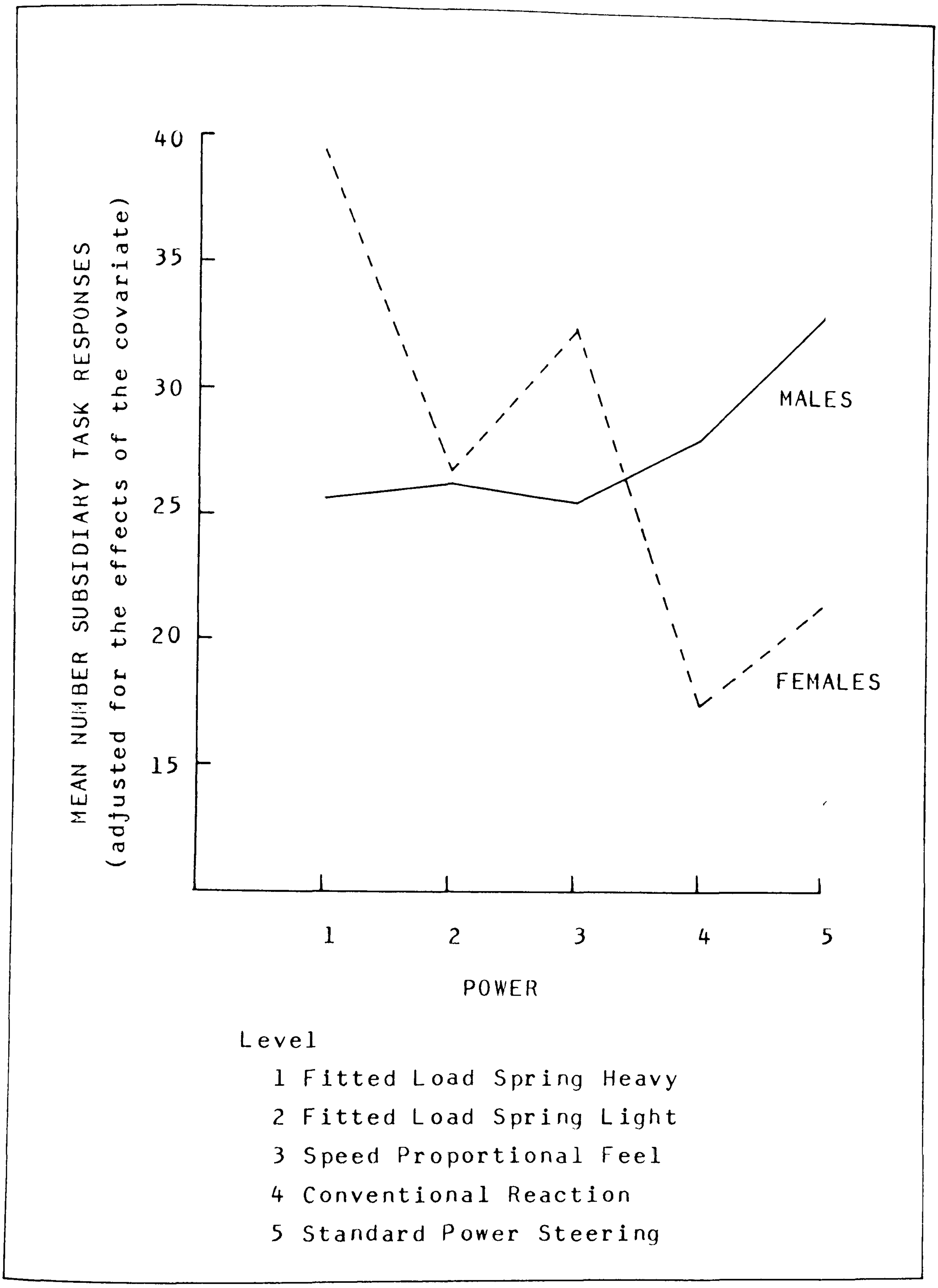


FIGURE 21. Graphic representation of the Power by Sex interaction from Analysis of Covariance 6. (No significant differences were found between Task 1 means so that only Task 2 means are plotted above). Data are from Test-track 2, dependent variable: Subsidiary task responses, covariate: Fine Steer.

Individual comparisons of the means associated with the weak but significant Power by Sex by Task interaction, est.ω^2 = .04, revealed no significant differences between Task 1 means with respect to the various levels of Sex or Power steering. Only Task 2 (subsidiary task) means are plotted for males and females in their respective power steering groups in Figure 21, therefore.Individual comparisons of males' subsidiary task means produced no significant differences between the power steering groups. There were significant differences between females' subsidiary task responses under Task 2 conditions, however, namely those between the Load Spring Heavy group (level 1) and both the Conventional Reaction and Control group (levels 4 and 5) $p < .01$, and also between the Speed Proportional Feel group (level 3) and the Conventional Reaction and Control groups, $p < .05$.

In considering the implications of this interaction, it should be remembered that a similar effect was noted in Analysis of Covariance 4, performed on subsidiary task data from Test-track 1. If the average of males' and females' mean scores is taken for each power steering group from Figure 21, a plot which is almost identical to that for the Power by Task 2 interaction shown in Figure 19 is produced. In other words, the weak Power by Sex by Task interaction found in the present analysis was, in all probability, due to a predisposition on the part of subjects allocated to some power steering groups to respond more frequently to the subsidiary task, rather than to the effects of the power steering systems themselves.

4.4.39 ANALYSIS OF COVARIANCE 7. DATA ARE SUBSIDIARY TASK SCORES FROM TEST-TRACK 2, COVARIATE: COARSE STEER.

The summary table for Analysis of Covariance 7 is given in Table 69, where it can be seen that the overall main effects of Order ($F = 6.2$, d.f. 3 and 269, $p < .01$), and Task ($F = 216.8$ d.f. 1 and 89, $p < .01$), and the Order by Task interaction ($F = 4.3$, d.f. 3 and 281, $p < .01$), were all found to be significant.

Adjusted means for the significant effects from Analysis of Covariance 7 are given in Table 70.

TABLE 69. Summary table for Analysis of Covariance 7. Data are subsidiary task responses from Test-track 2, covariate: Coarse Steer.

Source	SS	DF	MS	F	est ω^2
Power	1708.4	4	427.1	0.89	
Sex	0.1	1	0.1	0.00	
Power x Sex	4204.3	4	1051.1	2.18	
Covariates	544.0	1	544.0	1.13	
Residual	42868.1	89	481.7	29.36	
Order	294.2	3	98.0	6.17**	.05
Power x Order	291.0	12	24.2	1.52	
Sex x Order	35.9	3	11.9	0.75	
Power x Sex x Order	191.7	12	16.0	1.00	
Covariates	175.8	1	175.8	11.06	
Residual	4273.4	269	15.9	0.96	
Task	98279.0	1	98279.0	216.81**	.66
Power x Task	2039.0	4	509.8	1.12	
Sex x Task	29.8	1	29.8	0.07	
Power x Sex x Task	3717.3	4	929.3	2.05	
Covariates	3068.6	1	3068.6	6.77	
Residual	40343.6	89	453.3	27.63	
Order x Task	211.3	3	70.4	4.29**	.03
Power x Order x Task	323.5	12	27.0	1.64	
Sex x Order x Task	47.1	3	15.7	0.96	
Covariates	10.8	1	10.8	0.66	
Residual	4610.5	281	16.4		
Totals	207267.6	799			

** Indicates a value of F significant at the 1% level.

TABLE 70. Table of adjusted means from Analysis of Covariance 7. Data are subsidiary task responses from Test-track 2, covariate: Coarse Steer.

Factor	Level			
	1	2	3	4
Order	14.88	15.41	16.33	16.33
	No subsidiary task (1)		Subsidiary task (2)	
Task	1.56		29.91	
Task	No subsidiary task (1)		Subsidiary task (2)	
Order				
1	1.49		28.27	
2	1.37		29.44	
3	1.66		31.00	
4	1.73		30.94	

Reference to Table 70 indicates that the significant but weak Order effect, est.ω^2 = .05, was in the expected direction, greater numbers of subsidiary task responses being seen as the test-track session progressed. Individual comparisons of all pairs of means were significant at the one percent or five percent levels except those between Orders 1 and 2 and between Orders 3 and 4, which were non-significant.

The overall main effect of Task was also significant and relatively strong as expected, est.ω^2 = .66. Again, the Task effect is seen to be weaker after adjustment for the covariate reflecting the previously demonstrated effect of subsidiary task performance on drivers' coarse steering frequency.

Individual comparisons carried out on the means from the significant but weak Task by Order interaction, est.ω^2 = .03, indicate a similar effect to that reported previously. Thus, no significant differences were found between Task 1 (no subsidiary task) means, and the significant differences found between Task 2 (subsidiary task) means are the same as those found for the significant overall main effect of Order.

The overall main effects of Task and Order seen in previous Analyses of Covariance on Test-track 1 and Test-track 2 data are thus repeated in the present analysis.

4.4.40 ANALYSIS OF COVARIANCE 8. DATA ARE SUBSIDIARY TASK SCORES FROM TEST-TRACK 2, COVARIATES: TIME, FINE STEER AND COARSE STEER.

The summary table for Analysis of Covariance 8 is given in Table 71, where it can be seen that the overall main effects of Order ($F = 12.0$, d.f. 3 and 267, $p < .01$), and Task ($F = 82.8$, d.f. 1 and 87, $p < .01$), and the Order by Task interaction ($F = 3.8$, d.f. 3 and 279, $p < .01$), were all significant.

Adjusted means for the significant effects from Analysis of Covariance 8 are given in Table 72, and it can be seen that the significant but fairly weak Order effect, est.$\omega^2 = .09$, is in the expected direction, with increasing numbers of subsidiary task responses over Order. Individual comparisons of means were significant at the five percent or one percent levels for all pairs except that between Orders 3 and 4 which was non-significant. The Order by Task interaction was similar to that seen in previous analyses, in that no significant differences were found between Task 1 (no subsidiary task) means over Order, and the differences found between Task 2 (subsidiary task) means followed the same pattern as those of the main effect of Order.

Again the overall main effect of Task was found to be relatively weaker after adjustment for the covariates, est.$\omega^2 = .37$, reflecting the previously noted effects of the subsidiary task on drivers' test-track speeds, fine steering and coarse steering frequency.

Thus, in all the Analyses of Covariance conducted on Test-track 2 data, significant Task and Order effects were found after adjustment for all three covariates, both singly and together.

TABLE 71. Summary table for Analysis of Covariance 8. Data are subsidiary task responses from Test-track 2, covariates: Time, Fine Steer, Coarse Steer.

Source	SS	DF	MS	F	est ω^2
Power	1241.6	4	310.4	0.78	
Sex	1159.0	1	1159.0	2.92	
Power x Sex	2760.5	4	690.1	1.74	
Covariates	8920.0	3	2973.3	7.50	
Residual	34492.0	87	396.4	24.03	
Order	531.8	3	177.2	12.04**	.09
Power x Order	289.5	12	24.1	1.64	
Sex x Order	35.9	3	11.9	0.81	
Power x Sex x Order	191.3	12	15.9	1.08	
Covariates	519.3	3	173.1	11.76	
Residual	3929.8	267	14.7	0.89	
Task	28468.9	1	28468.9	82.83**	.37
Power x Task	2003.4	4	500.8	1.45	
Sex x Task	75.4	1	75.4	0.21	
Power x Sex x Task	2321.0	4	580.2	1.68	
Covariates	13512.8	3	4504.2	13.10	
Residual	29899.3	87	343.6	20.83	
Order x Task	189.9	3	63.3	3.83**	.03
Power x Order x Task	330.9	12	27.5	1.67	
Sex x Order x Task	42.6	3	14.2	0.86	
Covariates	18.3	3	6.1	0.37	
Residual	4603.0	279	16.5		
Totals	135537.2	799			

** Indicates a value of F significant at the 1% level.

TABLE 72. Table of adjusted means from Analysis of Covariance 8. Data are subsidiary task responses from Test-track 2, covariates: Time, Fine Steer, Coarse Steer.

Factor	Level			
	1	2	3	4
Order	14.23	15.35	16.55	16.82
	No subsidiary task (1)		Subsidiary task (2)	
Task	5.45		26.02	
Task	No subsidiary task (1)		Subsidiary task (2)	
Order				
1	4.79		23.67	
2	5.24		25.46	
3	5.71		27.38	
4	6.07		27.58	

When compared with the significant effects seen in the ordinary analysis of variance of Test-track 2 data, the result of including one or more covariates was generally to remove interaction effects, to increase the Order effect and decrease the strength of the Task effect.

4.5 DISCUSSION

Points of interest arising from the various analyses reported in the Results section are discussed below. The order in which the results are discussed will follow the order in which they were reported, that is, topics arising from the factor analyses are discussed first followed by those relating to the discriminant analyses and, finally, specific points arising from the analyses of variance and analyses of covariance will be considered.

4.5.1 FACTOR ANALYSES

The actual interpretation and meaning of individual factors has already received a good deal of attention and so will not be dwelt upon here, especially since the purpose of the factor analyses was their use as a data-reduction technique and to provide 'compound' variables for the subsequent discriminant analyses.

Two points concerning the interpretation of the factors should be reiterated, however. The first of these concerns the interpretation of factors as uni-polar dimensions, and the second concerns the simplification of the derived factors into 'NFactors', with the subsequent loss of orthogonality amongst the simplified NFactors.

It will be recalled from the Results section that reference was made to Overall and Klett's notion of a 'contrast' when interpreting the results of a principal components analysis. In the example given of an analysis of patients' psychiatric rating profiles, Overall and Klett note that the first component or factor derived is usually a general one with many variables positively weighted. Subsequent factors, however, formed contrasts, with some variables positively weighted and some negatively weighted. Thus, a factor having a negatively weighted variable 'A', and a positively weighted variable 'B', could be described as a contrast between patients who exhibit symptom 'A' and those who exhibit symptom 'B'. An alternative to the contrast notion was used to interpret the factors derived in the present work, however.

Since the coefficients used to define factors in terms of variables were also the product moment correlations between variable and factor, it was decided to interpret each factor as a uni-polar dimension to which variables were negatively or positively related. The meaning of a factor was then given in terms of the case of a high positive score on that factor. To return to the example used above, a high positive score would imply an individual's exhibiting a lot of symptom 'B', and a little of symptom 'A', since 'A' was negatively weighted and 'B' was positively weighted. This does not change the 'real' meaning of the factor of course, since a high negative score would imply an individual's exhibiting a lot of symptom 'A' and a little of symptom 'B', thus establishing the same contrast between symptom 'A' individuals and symptom 'B' individuals.

The purpose in adopting the interpretation of the derived factors in terms of a high positive score was simply to facilitate the interpretation of the discriminant functions which were the ultimate aim of the excercise. Rather than the results of the factor analyses describing an underlying psychological continuum as in the example used by Overall and Klett, the purpose of the factors derived in the present study was to provide descriptive variables for use in further analysis. Only when groups of individuals could be discriminated between on the basis of discriminant functions would it become necessary to consider the psychological implications of the factors.

The results of the factor analyses were, therefore, reported in terms of 'scores' rather than 'contrasts', and comments about factors' psychological meaning left until the factors were found to be useful in discriminating between groups as variables in the subsequent discriminant analyses.

The second point to be made about the interpretation of results of the factor analyses concerns the simplification of factors into NFactors and the lack of orthogonality between these. It will be recalled from the Results section that before being interpreted, the factors as derived by the computer analysis were first simplified into NFactors by selecting a subset of the most important variables. The selection of the most important variables was relatively easy, as the coefficients used to define the factors were also known to be the product moment correlation coefficients between variables and factors. Thus, only those variables having relatively high correlations with a given factor were used to define the simplified NFactors described in the Results section. In order to check that the simplified NFactors were close approximations of the original factors derived in the computer analysis, factor scores computed from the original factors and those computed from the simplified NFactors were correlated. The results (given in Appendix I) indicated that in most cases, the original factors and simplified NFactors were indeed highly related, an average value of r = .85 being obtained.

A second feature of the simplified NFactors which was mentioned briefly in the Results section, was their lack of orthogonality. Reference to the correlation coefficients computed among the NFactor scores (given in Appendid J) shows that some of the NFactors are significantly correlated. Some loss of orthogonality was to be expected by virtue of the fact that the simplified NFactors were defined in terms of a subset of the variables contributing to the original factors which were, by definition, statistically unrelated. It is apparent, however, that the use of the matrix of correlations between variables and factors to define the NFactors also contributed to this lack of orthogonality.

A number of matrices can be output from the SPSS 'Factor' subprogram which are relevant to the interpretation of factors. Two are of particular importance to the rotated solution and these are the 'factor pattern' or 'factor structure' matrix (since these are identical in the case of principal components analysis), and the 'factor score coefficient' matrix. The former matrix can be used to define factors in terms of variables, or variables in terms of factors and it contains correlation coefficients. The latter matrix contains the weights to be used in estimating factor scores from the standardized values of the relevent variables. The relationship between these two matrices is easily defined since the transpose of the factor score coefficient matrix is equal to the inverse of the factor pattern/factor structure matrix, that is $B' = A^{-1}$, where B is the factor score coefficient matrix and A is the factor pattern/factor structure matrix.

The decision to use the factor pattern/factor structure matrix in defining the simplified NFactors was made on the basis that it facilitated the selection of the most important variables used to define the NFactors. Whereas the correlation coefficients in the factor pattern/factor structure matrix allowed an evaluation of a variable's imporbance to a given factor on an absolute basis, (r^2 being a useful index of the variance in factor scores accounted for by the variable), the coefficients in the factor score matrix allow only an estimate of relative importance to be made. That is, a coefficient of high magnitude in the factor score coefficient matrix indicates only that the associated variable is more important than one with an associated coefficient of lower magnitude, but does not indicate by how much their importance differs. Using factor score coefficients to define factors and to estimate factor scores does have the advantage of producing statistically unrelated factors, however, and the loss of orthogonality seen among the NFactors defined in terms of the factor pattern/factor structure matrix is due, in large part, to the use of the latter matrix in their definition.

The importance of orthogonality of factors depends almost entirely on the use to which they are put, however. In the present case, no obvious advantage was to be gained by an insistance on orthogonality, since the use of discriminant analysis makes no assumptions about the independence of discriminant variables, and, conceptually, no problems were found in the interpretation of related factors.

To some extent of course, part of the information contained in statistically related factors is redundant, in that the same information may be contained in more than one factor. In some sense, therefore, a discriminant analysis carried out on orthogonal variables could be said to be more efficient than one carried out on variables which are related. The fact remains that the applications of discriminant analysis in psychology almost always involve the use of variables which are related. At least, in this case, the extent of that relation is known.

4.5.2 DISCRIMINANT ANALYSES

Those discriminant analyses which were carried out on the NFactors derived from the Questionnaire, Road-run and Test-track data combined, provided more effective discrimination of the experimental groups than those discriminant analyses carried out on the NFactors derived from the Questionnaire, Road-run and Test-track data considered separately. The discriminant analyses conducted on the combined NFactors from all three sources will be discussed in depth, therefore, although reference will be made to those analyses of NFactors from individual sources where these help to clarify interpretation.

Discriminant Analysis 4, which was based upon all NFactors from the first half of the experiment, that is, Questionnaire 'B', Road-run 1 and Test-track 1, and which took as its experimental groups males and females, addressed the question, "do males and females differ in their responses to the standard power assisted steering system?" The short answer to this question seems to have been "yes", since 91% of subjects were correctly classified as male or female on the basis of the single, significant, discriminant function derived. The canonical correlation of .78 also indicates that a relatively high proportion (61%) of the variance in discriminant scores was accounted for by the 'groups' variable, so that the subject's sex is seen as relatively important in predicting his response to power steering. It is not difficult to think of other factors which are likely to have contributed to variance in discriminant scores, for example, the subject's age and driving experience. Nevertheless, sex is seen as the single most important variable in accounting for the variance in scores on the derived discriminant function.

A number of interesting differences were found in Discriminant Analysis 4 between males' and females' responses to the standard power steering system. Most striking was males' willingness to manoeuvre the car in traffic whilst finding it difficult to position and to judge the effort required to steer the car.

One of the criticisms of power assisted steering, discussed earlier, is that it can make it difficult for the driver to anticipate the amount of effort required from him to steer the car under certain circumstances. This was attributed to the non-linearities in the handwheel torque/system pressure curve depicted in Figure 1, where at two points on the curve, there tend to be relatively large increases in system pressure or power assistance for relatively small increases in the forces applied to the steering wheel. Males' questionnaire responses certainly suggest that it was this characteristic of power assisted steering to which they reacted, hence the difficulty in positioning the car when making right angle turns and entering roundabouts, the difficulty in judging the effort required to steer the car at roundabouts and when turning sharply, the tendency to ''oversteer' and the detection of sudden changes in the amount of effort required to steer the car, (the component variables of NFactor 1A).

Despite the problems described above, however, male subjects also expressed an increased willingness to squeeze past slow moving vehicles, to 'nip in and out' around parked cars, and generally to manoeuvre the car in traffic, (the component variables of NFactor 3A). Thus, although males experienced some difficulty in getting used to power assisted steering, they were more willing to make manoeuvres in a car with power steering than in their own cars.

At higher speeds (represented by the 'flat' section of the curve in Figure 1) males felt more confident in the steering, and drove faster than the females, making fewer coarse steering reversals on the M1 and trunk roads.

Female subjects did not appear to experience any problems with the force characteristics of the standard power steering in traffic, finding it sensitive, responsive, with good 'feel', and finding it easy to judge the effort required to steer the car. They were, however, less willing to make manoeuvres in the experimental car than in their own cars, although they drove more quickly, making fewer steering wheel reversals over the largest section of town driving than male subjects.

Females also drove more slowly and made more coarse steering wheel reversals than males on the M1 and on a trunk road section of the route.

Males' and females' performance on the test-track is interesting on two counts. Firstly, the performance of the males could be said to be superior to that of the females, in that subjects were instructed to drive as quickly and accurately as possible on the test-track, and males did in fact drive faster and hit fewer cones than females. In order to determine whether this superior performance was due to a difference in driving experience or exposure between males and females, rather than reflecting a differential reaction to power assisted steering, a two-way (2x5) analysis of variance was carried out on the biographical data given in Appendix C. The results of this analysis indicate that there were no significant differences between males and females within the power steering groups with respect to age or the number of years subjects had driven. Similarly, Chi-square tests carried out on the numbers of drivers with previous experience of automatic transmission and with previous experience of power assisted steering also suggest that there were no significant differences between the sexes in each power steering group with respect to these variables. Whilst it might be expected that, in the general population, males would have a more extensive and wider driving experience than females, this does not appear to be true of the samples of drivers used in the present experiment. The observed differences in males' and females' test-track performances cannot be attributed to a differential level of driving experience, therefore.

Secondly, it is interesting to compare males' and females' test-track performance with their driving on the road. Whereas males tended to drive faster and make fewer coarse steering wheel reversals on the motorway and trunk roads, they also tended to drive more slowly and make more steering reversals than females in town driving. Contrasted with the male's demonstrated ability to drive faster and more accurately than females on the test-track, which was laid out to represent the types of manoeuvre carried out in normal town driving, it is possible to interpret females' faster driving in Bedford as being less safe than males'. It was certainly the Experimenter's impression that female subjects tended to drive more slowly than males on fast, open roads, but more quickly than their male counterparts in built-up suburban or urban areas, and this is partly borne out by the results of this analysis. It has been suggested elsewhere, Storie (1977), that male and female drivers tend to be involved in different types of accident. Typically, males were found to be involved in high speed accidents, for example, during overtaking manoeuvres. Females, on the other hand, were associated with low speed accidents which might take place at junctions and intersections, that is, in urban driving. Taken together, therefore, these results suggest that further research into males' and females' driving patterns in urban and highway driving may throw some light on the apparent differences in the types of accident in which they become involved.

The variables used in Discriminant Analysis 8 were the NFactors derived from Questionnaire 'C', Road-run 2 and Test-track 2, that is, the combined NFactors from the second half of the experiment, the experimental groups were again males and females.

It should be remembered that subjects were assigned to their respective power steering groups during the second part of the experiment, and this was put forward as a reason for the reduced effectiveness of the function derived in Discriminant Analysis 8, compared with that derived in Discriminant Analysis 4, to correctly classify subjects on the basis of sex alone. Thus, only 83% of males and females were correctly classified in terms of the NFactors from Questionnaire 'C', Road-run 2 and Test-track 2, whilst 91% of males and females were correctly classified in terms of the NFactors from Questionnaire 'B', Road-run 1 and Test-track 1. The function derived in Discriminant Analysis 8 was significant at the 1% level, and the canonical correlation coefficient of .67 indicated that approximately 45% of the variance in discriminant scores was accounted for by the 'groups' variable, that is, subjects' sex. This compares with a canonical correlation of .78, or 61% of the variance accounted for by subjects' sex associated with the function derived in Discriminant Analysis 4.

The most important variables in discriminating between males and females, irrespective of the particular power steering system to which they were assigned, were seen to be those from the test-track session. This was to be expected, however, since of the analyses conducted separately on Questionnaire 'C', Road-run 2 and Test-track 2, (Discriminant Analyses 5, 6 and 7 respectively), it was Discriminant Analysis 7, carried out on the NFactors from Test-track 2, which provided the best discrimination between the two experimental groups, and it was also the only analysis to yield a statistically significant discriminant function. Thus, males were distinguished from females on the basis of their driving faster and more accurately on the test-track and by their responding more frequently to the subsidiary task.

Although the NFactors derived from Questionnaire 'C' and Road-run 2 data did contribute to the discriminant power of the function, in that a greater number of subjects were correctly classified in Discriminant Analysis 8 (in which these variables were included) than in Discriminant Analysis 7 (in which they were not), their contribution was not readily interpreted. It must be remembered, however, that subjects had been assigned to their respective power steering groups in the second part of the experiment, so that their responses to the questionnaire and their driving on the road and test-track were open to the effects of different power steering characteristics. Whilst it was relatively easy to discriminate between males' and females' performance on the test-track in the second part of the experiment, therefore, it was not a simple matter to do so in terms of their questionnaire responses or their driving behaviour on the road. The implications of these findings, which are borne out by later analyses, is that in the second part of the experiment, the subject's sex was a relatively important determinant of test-track driving performance, but that the type of power steering in use was a more important determinant of the subject's response to the questionnaire and his road driving performance.

A final point of interest with respect to the results of Discriminant Analysis 8, is that the previously noted differences in males' and females' driving speeds in urban and highway driving has virtually disappeared. The results of Discriminant Analysis 4 indicated that males drove significantly faster than females on the M1 and trunk roads, and that females drove significantly faster than males over the largest section of urban roads during the first road-run. (The univariate F ratios for these variables were significant.) It was suggested that these findings were consonant with those of other workers concerning the types of accident typically experienced by male and female drivers. On the second road-run, however, the only indication of a difference between males' and females' driving speeds was that, on the last section of the route, males were associated with significantly shorter driving times than females. It is not possible to determine whether the absence of a relationship between sex and driving speed during the second road-run was due to the effects of the experimental power steering systems, the increased familiarity of subjects with the experimental car, or perhaps, both of these factors.

Of the eight discriminant analyses which sought to discriminate between several experimental groups, three produced functions which were significant at the one percent level, and two produced functions which were described as "marginally significant". Furthermore, as was found to be the case with the earlier analyses which sought to discriminate between males and females, analyses discriminating between many experimental groups were more likely to produce significant discriminant functions when based upon several data sources than when based upon a single data source.

Thus, Discriminant Analysis 10, which sought to discriminate between the five power steering groups on the basis of NFactors derived from Road-run 2, produced a single function which was only marginally significant, $p = .08$. Discriminant Analysis 12, on the other hand, which sought to discriminate between the five power steering groups on the basis of NFactors derived from all three data sources (Questionnaire 'C', Road-run 2 and Test-track 2) produced two significant functions which were significant at the 1% level. Similarly, Discriminant Analysis 14, which sought to discriminate between 10 experimental groups on the basis of the NFactors derived from Road-run 2 data, produced one function which was marginally significant, $p = .10$. Discriminant Analysis 16, on the other hand, which also sought to discriminate between 10 groups, but which was based on all three data sources, produced two functions significant at the 1% level, and one function which was marginally significant.

Although the functions derived in Discriminant Analyses 10 and 14 were only marginally significant, these analyses will be discussed next as they have many features in common, and they can be related to the earlier discriminant analyses of the NFactors derived from Road-run 2 data in which the discriminant groups were males and females. A discussion of Discriminant Analyses 12 and 16, probably the most important of the series, will follow.

Discriminant Analysis 10 provided four functions, on the basis of which 47% of cases were correctly classified. A canonical correlation of .56 for the first, marginally significant, function indicated that 31% of the variance in subjects' discriminant scores was accounted for by the 'power steering groups' variable. This function permitted the Control group to be discriminated from the other power steering groups and, to some extent, the Speed Proportional Feel group from both the Control group and the other power steering groups.

The positive scores of the Control group were found to be associated with making more coarse steering wheel reversals on the M1 and trunk roads, driving faster and making fewer reversals on some urban and suburban sections of the route and with making more fine steering reversals overall. The negative scores of the Load Spring groups and the Conventional Reaction group were associated with making fewer coarse steering reversals on the M1 and trunk roads, with driving more slowly and making more reversals on some urban and suburban sections of the route, and with making fewer fine steering reversals overall. The Speed Proportional Feel group centroid was almost zero on the function.

It would seem that the Control group was separated from the Load Spring and Conventional Reaction groups on the basis of subjects' differing driving patterns under differing driving conditions. Thus the Control Group tended to make more coarse steering reversals than the other groups on higher speed and relatively straight sections of the route, whilst driving faster and making fewer reversals than the other groups on the lower speed urban and suburban sections of the route, making more fine steering reversals overall. It was perhaps to be expected that the 'heavier' Load Spring and Conventional Reaction systems would be associated with drivers making fewer coarse steering reversals at speed and with making fewer fine steering reversals, but not necessarily that they should be associated with driving more slowly and making more steering reversals in urban and suburban driving. The Speed Proportional Feel group, which might have been expected to behave in a similar way to the Load Spring groups at speed and the Control group at lower speeds was, thus, appropriately placed at the mid-point of the function.

The apparent anomalies in the Load Spring and Conventional Reaction groups' behaviour at lower speeds are largely explained by the relative contributions of males and females to the overall position of the group centroid, and this is reflected in the function derived in Discriminant Analysis 14, (see Table 33). A comparison of Tables 24 and 33 shows that the last function derived in Discriminant Analysis 10 and that derived in Discriminant Analysis 14 are almost identical. This was to have been expected of course, as both analyses were conducted on the same data, the only difference being that the five discriminant groups appearing in Discriminant Analysis 10 included male and female subjects assigned to each power steering system, whereas the ten discriminant groups appearing in Discriminant Analysis 14 considered males and females separately within each power steering system.

Given that the functions derived in Discriminant Analyses 10 and 14 can be regarded as one and the same, therefore, the relative contributions of males and females to the positions of power steering group centroids on the function derived in Discriminant Analysis 10 become clear. Comparison of Figures 6 and 8 shows that males tended to contribute negative scores and females positive scores. The position of a given power steering group centroid on the function derived in Discriminant Analysis 10, therefore, lies mid-way between the centroids of males and females within the power steering group on the function derived in Discriminant Analysis 14. Thus, the centroid of group 1 in Figure 6 is at a point mid-way between the centroids of groups 1 and 2 in Figure 8. Similarly, group 2 in Figure 6 lies between the centroids of groups 3 and 4 in Figure 8, and so on. Only in the case of the Control group (group 5 in Figure 6 and groups 9 and 10 in Figure 8) were males' and females' reactions to the steering system almost identical.

Whereas both Fitted Load Spring groups in Discriminant Analysis 10 were associated with making fewer coarse steering reversals on the M1 and trunk roads, driving more slowly and making more reversals on urban and suburban sections and with making fewer fine steering reversals overall, it can be seen from Discriminant Analysis 14 that it was only male subjects in the Load Spring groups who behaved in this way. Females tended to make more coarse steering reversals on the M1 and trunk roads, to drive faster and to make fewer steering reversals in urban areas and to make more fine steering reversals overall. Similarly, the position of the Speed Proportional Feel Group at the mid-point of the function in Discriminant Analysis 10 can be seen to be reflected in males' negative scores and females' positive scores on the function derived in Discriminant Analysis 14. In the case of males and females in the Control group, and to a lesser extent in the Conventional Reaction group, a much closer agreement in terms of the position of group centroids on the function derived in Discriminant Analysis 14 is apparent. Comments made about the Control group and Conventional Reaction group as a result of Discriminant Analysis 10 can be applied equally to both male and female subjects in those groups.

It is fairly clear from the findings of Discriminant Analysis 14, that the earlier analyses of the NFactors derived from Road-run 2 data with respect to males and females (Discriminant Analysis 6) and with respect to the five power steering groups (Discriminant Analysis 10) were relatively unsuccessful because males and females within power steering groups tended to behave differently. The fact that males and females did react similarly in two of the power steering groups however, (the Conventional Reaction and Control groups), meant that some discrimination was possible between power steering systems. Similarly, the fact that males and females responded differently, males tending to have negative scores and females positive scores on the functions derived in Discriminant Analyses 10 and 14, also meant that some discrimination was possible on the basis of subjects' sex. The ability to discriminate between the sexes in terms of the NFactors from Road-run 2 was, of course, anticipated in the results of Discriminant Analysis 6, in which males were associated with making fewer coarse steering reversals and driving more slowly on the M1 and trunk roads, driving more slowly and making more reversals over other sections of the route and making fewer fine steering reversals overall than females.

The analyses to be discussed next are Discriminant Analyses 12 and 16 which are also complementary in the sense that they are based upon the same data sources but involve different discriminant groups.

Discriminant Analysis 12, based on all the NFactors from the second part of the experiment, provided two statistically significant discriminant functions. The percentage of cases correctly classified on the basis of all four functions was 66%, which was lower than the percentage of cases correctly classified in the previous multi-source analyses. (Discriminant Analysis 4 correctly classified 91% and Discriminant Analysis 8 correctly classified 83% of subjects.) However, the inclusion of five experimental groups in Discriminant Analysis 12 means that only 20% of subjects would be expected to be correctly classified on the basis of chance alone, whereas the two experimental groups in Discriminant Analyses 4 and 8 meant that 50% correct classifications would be expected by chance. Placed in context, therefore, 66% of cases correctly classified in Analysis 12 represents a significant proportion.

The canonical correlations reported in the Results section also suggest that the power steering group to which a subject was assigned was relatively more important than the subject's sex in providing a basis on which to discriminate between groups when all three data sources are used.

Thus, it was seen that 47% of the variance in scores on the single discriminant function derived in Discriminant Analysis 8 was accounted for by the 'groups' variable (sex), whereas 50% of the variance on function 1, and 36% of variance in scores on function 2 from Discriminant Analysis 12 was accounted for by the 'groups' variable (power steering).

The first function reported in Discriminant Analysis 12 indicated that the Fitted Load Spring groups and the Conventional Reaction group had described the steering as "too heavy" and "different", and that the Control group and Speed Proportional Feel group had described the steering as "too light" and "no different". Furthermore, the Load Spring Heavy group was placed closer to the extreme "too heavy" and "different" end of the dimension than was the Load Spring Light group, and the Control group was placed closer to the "too light" and "no different" end of the function than the Speed Proportional Feel group. These results were seen to be entirely appropriate in view of the design features of the particular systems with which they were associated.

Thus, the Fitted Load Spring systems, which were intended to give a constantly heavier 'feel' than the standard power steering, were placed in the order of their 'heaviness' on function 1. Similarly, the Conventional Reaction system, which was designed to simulate unassisted steering in its force characteristics, and which became heaviest at very low speeds, was placed in a less extreme position at the "too heavy" and "different" end of the dimension than either of the Fitted Load Spring groups. In the same way, the Control group and the Speed Proportional Feel group were placed towards the "too light" and "no different" end of function 1, the more extreme position being occupied by the Control group whose standard power steering system was indeed no different in the second half of the experiment than it had been in the first half.

It is interesting to note that the two variable assistance characteristics, the Conventional Reaction and Speed Proportional Feel systems, were placed closer to the middle or zero point on function 1 than the constant feel systems or Control groups. This presumably reflects the fact that the two variable feel systems were not found to be consistently "too light" and "too heavy", but were different under different conditions, and this view is supported by these systems' opposite and extreme positions on function 2. Thus, the Speed Proportional Feel group was associated with subjective feelings of driving faster and overtaking more and with finding it easier to maintain lane position on the motorway, while the Conventional Reaction group was associated with feelings of driving more slowly, overtaking less and finding it harder to maintain their lane position on the motorway. That is to say, the two systems were differentiated in terms of the driving situation, the Speed Proportional Feel system being related to confidence at speed and the Conventional Reaction system being associated with a lack of confidence at speed. In the case of the Speed Proportional Feel system, the designer's aim was to improve 'feel' at higher speeds, and it may well be that drivers' feelings of confidence at speed and their finding it easier to maintain lane position reflects this design feature of the system. The topic of subjects' response to the Speed Proportional Feel system and its design features are discussed in more detail later in this section.

The Load Spring groups and Control group had relatively low scores on the second function from Discriminant Analysis 12. The Control group and Load Spring Light group's low negative scores on the function were associated with feelings of the steering being too light and no different, of driving more slowly and overtaking less, of having difficulty in maintaining lane position and a lack of confidence at speed. It would seem that the Load Spring Light system was not sufficiently different from the standard power steering system for it to be discriminated from the Control group on function 2. The Load Spring Heavy system, however, was associated with feelings of the steering being too heavy and different, of driving faster and overtaking more, of being easier to maintain lane position and confidence at speed. It is interesting to note that the Load Spring Heavy system was associated with a less extreme score on function 2 than the Speed Proportional Feel system, when the constant artificial 'feel' characteristic of the Load Spring system might have been expected to place it in a more extreme position relative to the variable 'feel' characteristic of the Speed Proportional Feel system.

Although the first function derived in Discriminant Analysis 16 is similar to the first function derived in Discriminant Analysis 12, and functions two and three from Discriminant Analysis 16 are both similar to the second function derived in Discriminant Analysis 12, there are a sufficient number of differences between the functions derived in the two analyses to warrant a separate discussion.

Discriminant Analysis 16, was carried out on all the NFactors from the second half of the experiment, and it took as its discriminant groups each of the power steering groups further divided into males and females. The analysis produced two significant functions at the 1% level, and a third, marginally significant function, $p = .09$. As was seen in the Results section, 63% of subjects were correctly classified on the basis of the functions derived in Discriminant Analysis 16 when one would expect only 10% to be correctly classified by chance. The canonical correlations given indicated that an average of 50% of the variance in scores on each discriminant function was accounted for by the 'groups' variable.

In a sense, Discriminant Analysis 16 was the single most important discriminant analysis to be carried out, since it included both male and female groups of subjects within their respective power assisted steering groups. It is fortunate, therefore, that despite the fact that males and females had been seen to respond differently to power assisted steering in previous analyses, the first function derived in Discriminant Analysis 16 was both significant and succeeded in discriminating between power steering systems. The second function, which was also significant, discriminated between males and females irrespective of power steering groups, and the third function, which was only marginally significant, provided a more general dimension and did not appear to discriminate between groups in terms of power steering or sex.

The fact that the first function to be derived in this analysis discriminated between power steering groups, and the second function discriminated between males and females, underlines the point made in the Results section that it was easier to discriminate between groups of subjects in terms of the power steering system to which they had been allocated than in terms of their sex when the NFactors from all data sources were included.

The variables associated with discriminant function one were seen to be related to different driving conditions. Thus, on high speed relatively straight roads, subjects in the Load Spring groups and Conventional Reaction group were associated with driving faster and making fewer steering reversals than subjects in the Control group and Speed Proportional Feel group. However, on lower speed roads, the Load Spring groups and the

Conventional Reaction group were associated with driving more slowly and making more reversals than the Control group and Speed Proportional Feel group and with hitting more cones on the test-track.

The above findings are essentially those of function 1 from Discriminant Analysis 12. If the average position of the male and the female group centroids on the first function from Discriminant Analysis 16 is taken, (see Figure 10), it will be seen that, for a given power steering group, a close correspondence exists with the position of that power steering group's centroid on function one of Discriminant Analysis 12, (see Figure 7).

Although both males and females within a power steering group were found to have either positive or negative scores on function 1, within some power steering groups, namely the Load Spring Heavy, Speed Proportional Feel and the Control groups, males and females were placed some distance apart. In two cases, those of the Load Spring Heavy group and the Speed Proportional Feel group, males had higher absolute scores than females, and in the case of the Control group, females were seen to have higher absolute scores on the function than males. It is not clear, therefore, how to interpret the apparent differences between males and females on function 1.

Fortunately, the second function derived in Discriminant Analysis 16 successfully distinguished between males and females irrespective of power steering system. Not surprisingly, there was a close resemblance between the second function derived in this analysis and the single function derived in Discriminant Analysis 8 which was carried out on the same data but for males and females only. On function two, therefore, male subjects were associated with finding the steering less responsive and sensitive, more difficult to position in town driving, but with driving faster and more accurately on the test-track and responding more frequently to the subsidiary task. Males also felt more confident and found it easier to maintain lane position at higher speeds. Females tended to find the steering more sensitive and responsive, easier to position in traffic, whilst driving more slowly and less accurately on the test-track and responding less frequently to the subsidiary task. Females also felt less confident and had more difficulty in maintaining their lane position at higher speeds.

In general, the second function from Discriminant Analysis 16 reiterates the findings of previous analyses in which males and females were discriminated between on the basis of all data sources, that is, NFactors from the questionnaire, road-run and test-track. These findings can be summarized fairly briefly with respect to males who were associated with finding it easy to maintain their lane position and having confidence at speed, finding it difficult to position the car in town driving, and driving faster and more accurately on the test-track. Conversely females were associated with finding it difficult to maintain their lane position and lacking confidence at speed, finding it easier to position the car in town driving but driving more slowly and less accurately than male subjects on the test-track.

Two points are worthy of note in considering the second function from Discriminant Analysis 16. Firstly, although males were associated with feeling more confident at speed, and finding it easier to maintain their lane position on the motorway, they did not drive any faster than females on the motorway. It may be recalled that, in the analysis of NFactors derived from Road-run 1 (Discriminant Analysis 2), males did in fact drive significantly faster than females on the motorway but females drove significantly faster than males in urban areas. Secondly, although females were associated with finding the car easier to position in town driving, they drove no faster than males in town, and drove more slowly and less accurately than males on the test-track. It would seem to be the case, therefore, that the subject's confidence in the steering and the ease with which he was able to position the car was not reflected in how fast he drove on Road-run 2. Similarly, there appears to be no direct relationship between the speed with which the subject drove in town and his ability to drive accurately and at speed on the test-track. (This was confirmed by calculating the Pearson Product Moment Correlation coefficient between subjects' test-track speeds and driving speeds in Bedford. The resulting value of $r = -.16$ was non-significant.)

In the discussion of the results of Discriminant Analysis 4, it was suggested that females' faster driving in town and their poorer performance in terms of speed and accuracy on the test-track could be taken to indicate that females were driving less safely than males. Although males and females do not appear to have driven at different speeds on the motorway or in town on Road-run 2, females' finding it easier to position the car in town driving and subsequent poorer performance on the test-track may again be indicative of less safe driving, given that they drove at the same speed in town as males. Further, females' willingness to drive at the same speed as males on the motorway, given that they expressed a lack of confidence at speed and found it more difficult to maintain their lane position, may also be interpreted in a similar way.

The third function derived in Discriminant Analysis 16 was found to be more general, in that, positive scores on the function appeared to be associated with largely favourable subjective ratings, and negative scores on the function with largely unfavourable ratings. Thus, the positive scores of the males in the Load Spring Heavy group, and females in the Speed Proportional Feel and Control groups were associated with the steering's being sensitive, responsive, easy to position, with a lack of play, subjective feelings of driving faster and overtaking more, ease of control, ease of maintaining lane-position on the motorway and confidence at speed. The negative scores of the males in the Load Spring Light group, and males and females in the Conventional Reaction group on the other hand, were associated with the steering's lack of sensitivity, responsiveness and being difficult to position, with play in steering, the impression of driving more slowly and overtaking less, being more difficult to control, with difficulty in maintaining lane position on the motorway and with a lack of confidence at speed. Females in both Load

Spring groups and males in the Speed Proportional Feel and Control groups were associated with very small positive scores on function 3, so that they may be thought of as having neither generally favourable nor generally unfavourable reactions to the steering.

4.5.3 THE SPECIFICATION OF AN OPTIMAL POWER STEERING CHARACTERISTIC.

Having discussed in some detail the discriminant analyses of primary interest, it is appropriate to consider the implications of these analyses for the selection of the 'optimal' power steering characteristic. In this respect, the results of Discriminant Analyses 12 and 16 are most relevant, as all groups of subjects were represented in these analyses, and all three data sources were employed.

Two problems are immediately encountered in specifying the optimal power steering characteristic on the basis of these results, however. The first concerns the definition of 'optimal', that is, on what basis should one system be selected in preference to the others? The second problem arises from the different reactions of males and females to a given power assisted steering system, further complicating the choice of a single 'optimal' system.

In order to address the first problem, that is, to find a basis on which one system may be selected in preference to the others, reference will be made to the results of Discriminant Analysis 12, since this analysis considered power steering groups without taking subjects' sex into account.

The first task in providing criteria on which to specify the optimal system is that of deciding which of the discriminant variables from the analysis represent desirable characteristics and which undesirable characteristics. This implies a series of value judgements, and whether or not a variable is considered 'desirable' depends very much upon the judge's point of view. For example, a variable such as "driving faster and making fewer coarse steering reversals on the motorway" is difficult to evaluate in an absolute sense. The designer of a high performance car would presumably regard this as a desirable characteristic of a power steering system, but those concerned with road safety might well regard "driving faster and making fewer coarse steering reversals on the motorway" as an undesirable characteristic.

Assuming, for the sake of argument, that a decision is made to regard "driving faster" as a desirable characteristic, a further problem is then encountered in that, on some functions, this variable is specific to a given situation. For example, on the first function in Discriminant Analysis 12, positive scores are associated with driving faster and making fewer reversals on the motorway, but with driving more slowly on rural and urban roads, and with making more steering reversals on suburban sections of the route. In considering the position of a power steering group on function 1, therefore, it would seem that both positive scores and negative scores are associated with some desirable and some undesirable characteristics. As a first step to selecting the optimal power steering characteristic on the basis of function 1, therefore, the wisest course might be to exclude those systems having extreme scores in either direction.

If reference is made to Figure 8, it can be seen that power steering groups 1 and 5, the Load Spring Heavy group and the Control group, have the most extreme scores on the function, with group 3, the Speed Proportional Feel group having a moderately high negative score, and groups 2 and 4, the Load Spring Light and Conventional Reaction groups respectively, having moderately high positive scores. If the criterion for making a preliminary choice based on the undesirability of extreme scores is adopted, therefore, the Control group, (standard power steering) and the Load Spring Heavy system are excluded from further consideration.

If attention is now focussed on the second function from Discriminant Analysis 12 as a basis on which to specify the optimal characteristic from the remaining three power steering systems, it will be seen that a decision as to which variables associated with the function are desirable and which are undesirable is more easily made.

The variables associated with function 2 are largely those NFactors derived from Questionnaire 'C' which reflect the subjective assessments of drivers. Positive scores on function 2 indicate that subjects found the steering "heavier" and "different" from the standard power steering, felt that they drove faster and overtook more, felt more confident at speed, found it easier to maintain their lane position on the motorway and found the steering sensitive and responsive. In addition to these variables derived from Questionnaire 'C', positive scores on function 2 were also associated with driving faster and making fewer reversals on a section of the route containing an awkwardly shaped roundabout.

It would seem that positive scores on function 2 indicate a generally more favourable reaction to the steering than negative scores, which were associated with subjective impressions of the steerings being light and no different, of driving slowly and overtaking less, with difficulty in maintaining lane position on the motorway, with a lack of confidence at speed, and with less sensitive and responsive steering. Negative scores were also associated with driving more slowly and making more steering reversals at Kempston roundabout. Of those systems still being considered, group three, allocated to the Speed Proportional Feel system has the highest positive score on function 2, and is, therefore, selected as the optimal characteristic in terms of the criteria developed in this discussion.

With respect to the second problem identified above, that is, the difficulty in specifying the optimal power steering system arising from the different responses of males and females, reference must be made to the result of Discriminant Analysis 16, in which males and females within their respective power steering groups were considered.

From Figures 10 and 11 it can be seen that males and females in the Speed Proportional Feel group are placed some distance apart on functions 1 and 2, and relatively close together on function 3.

The Speed Proportional Feel system is unique, however, in that it is the only power steering system represented by the discriminant groups shown in Figure 10 which has both male and female group centroids falling in the same quadrant formed by the two axes. Thus, both males and females in the Speed Proportional Feel group have negative scores on function 1 and positive scores on function 2 from Discriminant Analysis 16. The fact that females have higher negative scores than males on function 1, and males have higher positive scores on function 2, however, indicates that these two groups did respond differently to the Speed Proportional Feel system.

Earlier in this discussion it was remarked that function 1 from Discriminant Analysis 12 and function 1 from Discriminant Analysis 16 were very similar, and that this was to be expected since both analyses were based upon the same data sources. In specifying the optimal power steering characteristic on the basis of Discriminant Analysis 12, it was also suggested that extreme scores on function 1 were undesirable. If the same criterion is adopted in the present analysis, it would seem that males reacted more favourably than females to the Speed Proportional Feel system since they had less extreme scores on the function.

Although the second function derived in Discriminant Analysis 16 had less in common with function 2 from Discriminant Analysis 12, it is fairly clear that positive scores on function 2 are associated with more favourable subjective ratings than negative scores. The variable associated with positive scores were a lack of sensitivity and responsiveness in the steering, finding it difficult to position, hitting fewer cones on the test-track, finding it easier to maintain lane position and feeling more confident at speed, driving faster on the test-track, finding it easy to tell how much grip there was at the front wheels, holding back more, making more subsidiary task responses on the test-track and more reversals on trial 1. Since males had higher positive scores than females on function 2, it would seem that they also responded more favourably to the Speed Proportional Feel System on the basis of this function.

Positive and negative scores on function 3 from Discriminant Analysis 16 can also be described fairly unequivocally in terms of the desirability of their component variables. Again positive scores on this function represent a more favourable reaction from drivers, being associated with finding the steering sensitive, responsive and easy to position, a lack of play, the impression of driving faster and overtaking more, with the car's being easier to control, driving faster and making fewer reversals in Ampthill, finding it easier to maintain lane position on the motorway and with having confidence at speed. In this case, females' slightly higher positive scores on the function indicate a more favourable reaction on their part.

4.5.4. DISCUSSION OF THE OPTIMAL CHARACTERISTIC IN TERMS OF ITS KNOWN DESIGN FEATURES.

Having argued, on the basis of the result of Discriminant Analysis 12, that subjects assigned to the Speed Proportional Feel system reacted more favourably to the steering than those assigned to the other systems, and, on the basis of the results of Discriminant Analysis 16, that males in the Speed Proportional Feel group reacted more favourably to the steering than females, it is necessary to consider the implications of these arguments with reference to the known design features of the system.

It may be recalled from the Introduction that the designer's aim in producing a Speed Proportional Feel system was to provide 'on-centre feel' at speed. Thus, by introducing an artificial resistance to the movement of the steering wheel at increasing speed, it was anticipated that the driver would be less likely to make inadvertent steering movements, and find it easier to keep 'on course' on straight fast roads. It was suggested in the Introduction that a Speed Proportional Feel system would provide a means of overcoming the 'sneeze factor' often associated with power assisted steering, and it was noted that other manufacturers beside Cam Gears had adopted similar principles in the design of their power steering systems.

On an a priori basis, therefore, subjects in the Speed Proportional Feel groups would be expected to have higher scores on variables such as driving faster and making fewer reversals on the motorway and trunk roads, finding it easier to maintain their lane position on the motorway and having confidence in the steering at speed, and finding the steering heavier and different. Any advantages detected by subjects would also be expected to diminish at lower speeds, so that the Speed Proportional Feel system would not necessarily be associated with variables such as driving faster and making fewer reversals in urban driving or on the test-track.

With respect to the results of Disciminant Analysis 12, subjects did not appear to respond to the Speed Proportional Feel system in the expected way on function 1. From Figure 7 it can be seen that the Speed Proportional Feel group's moderate negative scores on the function were associated with the steering being too light and no different, with driving more slowly on the last section of the route, with making more coarse steering reversals on the motorway and trunk roads, with driving faster on rural and urban roads, and with driving faster and making fewer reversals on suburban roads.

Although the variables associated with the Speed Proportional Feel group on function 1 of Discriminant Analysis 12 were almost the reverse of those anticipated on an a priori basis, those variables associated with the system with respect to function 2 were more in keeping with the a priori predictions.

On function 2, therefore, the Speed Proportional Feel group was associated with the steering being too heavy and different, with the impression of driving faster and overtaking more, with finding it easier to maintain lane position and having confidence at speed, and with driving faster and making fewer reversals at Kempston roundabout.

With respect to the results of Disciminant Analysis 16, it can be seen from Figures 10, 11 and 12 that males and females in the Speed Proportional Feel group again tended to respond in a manner contrary to expectations on function 1, but more predictably in terms of the variables associated with functions 2 and 3.

On function 1, females and to a lesser extent males were associated with driving more slowly on the last section of the route, making more reversals on trunk roads and the motorway, with the steering being too light and no different, with driving faster and making fewer reversals on a suburban section of the route and with hitting fewer cones on the test-track.

On function 2, males and to a lesser extent females, were associated with finding the steering lacking in sensitivity, responsiveness and being difficult to position, with hitting fewer cones on the test-track, with finding it easier to maintain their lane position and having confidence at speed, and driving faster on the test-track.

On the third function from Discriminant Analysis 16, females, and to a lesser extent males, were associated with finding the steering sensitive, responsive, and easy to position, and with a lack of play, with the impression of driving faster, overtaking more and with finding it easier to maintain their lane position and having confidence at speed.

In assessing the relative importance of each of the functions derived in the discriminant analyses discussed above, it should be remembered that each function derived accounts for progressively less of the total variance in discriminant scores. In the case of Discriminant Analysis 12, the two functions reported accounted for 46% and 26% of the total variance respectively. In the case of Discriminant Analysis 16, the three functions reported accounted for 29%, 26% and 16% of the total variance respectively. Although the variables associated with the Speed Proportional Feel group on function 2 from Discriminant Analysis 12, and from functions 2 and 3 from Discriminant Analysis 16, were found to be more appropriate in view of the known design characteristics of the system, the variables associated with the first functions derived in the two analyses were more 'important' in the sense that they accounted for a greater amount of the total variance in subjects' discriminant scores.

From this review of the results of Discriminant Analyses 12 and 16 in the light of the known design characteristics of the Speed Proportional Feel system, it would seem that drivers did not respond entirely in the manner expected, although males appear to have responded more predictably than females. To be more specific, the position of the Speed Proportional Feel group on the first function derived in both Discriminant Analysis 12 and Discriminant Analysis 16 does not agree with that which would have been predicted from a knowledge of the design characteristics of the system. Although the Speed Proportional Feel group's position on the remaining functions discussed was found to be much more appropriate to the designer's aims in producing the system, these functions are slightly less important in terms of the amount of discriminant variance accounted for. A closer look at the first functions derived in Discriminant Analysis 12 and Discriminant Analysis 16 is required, therefore, to resolve the apparent discrepancy between drivers' expected and actual response to the Speed Proportional Feel system.

From Figures 7 and 10 it can be seen that the Speed Proportional Feel group and Control group are both associated with negative scores on function 1 from Discriminant Analysis 12 and function 1 from Discriminant Analysis 16, whilst the remaining three power steering groups all have positive scores.

It may be recalled from the Introduction that each of the power steering characteristics used in the study was, in essence, a variation of the standard power steering system. That is, the artificial 'feel' characteristics of each system were superimposed upon those of the standard power steering. In the case of the Speed Proportional Feel system, the fact that the level of artificial 'feel' generated was proportional to vehicle speed meant that, at low speeds, the system behaved almost identically to the standard power steering. This may go some way to explaining why, in Figures 7 and 10, the Speed Proportional

Feel group and Control group are shown to be closely associated in terms of their positions on function 1.

It is also important to note, however, that the negative scores of the Control group and Speed Proportional Feel group serve to distinguish them from the Conventional Reaction group and the two Load Spring groups who have positive scores on the first functions from Discriminant Analyses 12 and 16. The variables associated with the Speed Proportional Feel group's negative score have been described as almost the reverse of those expected, and it is clear that positive scores on these functions would have been more in keeping with a priori predictions for the Speed Proportional Feel group. It would seem, therefore, that the positive scores of the Conventional Reaction and Load Spring groups indicate that these systems were more successful in producing the effects it was expected would be associated with the Speed Proportional Feel system, than the Speed Proportional Feel system itself.

The power steering groups with the highest positive scores on function 1 from Discriminant Analysis 12 and function 1 from Discriminant Analysis 16 are the Fitted Load Spring groups, the Load Spring Heavy group having a more extreme score than the Load Spring Light group. The essential feature of both these systems was that of a constant increase in the 'heaviness' of the steering in comparison with the standard power steering.

Although the maximum pressure applied to the torsion bar balls in both the Speed Proportional Feel system and the Load Spring Heavy system was nominally the same, the variable nature of the 'feel' characteristics of the former system and the constant 'feel' characteristics of the latter system presumably account for the differences seen in drivers' behaviour.

The effect of a constant artificial 'feel' in the case of the Load Spring Heavy group, appears to have been to increase drivers' confidence at moderate to high speeds, such that they were associated with driving faster on the last section of the route, and making fewer coarse steering reversals on trunk roads and the motorway. In addition, however, the heavier steering of the Load Spring Heavy system at lower speeds appears to have encouraged slower driving on rural and urban roads, to increase the number of cones hit by drivers on the test-track, and the number of steering reversals made on suburban roads.

In the case of the Speed Proportional Feel system, the effect of a variable artificial 'feel' appears to have been to make drivers less confident at moderate to high speeds, encouraging them to drive more slowly on the last section of the route, and to make more steering reversals on trunk roads and the motorway. It also appears to have enabled drivers to drive faster and make fewer reversals under rural, urban and suburban driving conditions, however, and to hit fewer cones on the test-track.

It seems likely, therefore, that the aim of the designer in producing a Speed Proportional Feel system might be more nearly met by a modification of the present system to adopt certain characteristics of the Load Spring Heavy system, that is, a higher level of artificial feel at relatively low speeds.

In fact, such a modification is easily made on the Cam Gears Speed Proportional Feel system, which incorporates a valve to regulate the level of artificial 'feel' as speed increases. By adjusting this valve, so that the maximum artificial feel is attained at, say, 64 k/h instead of the present 96 k/h, it seems likely that the driver would have more confidence in the steering at speed, whilst maintaining his ability to manoeuvre easily in urban driving and at very low speeds. In short, by introducing a higher level of artificial 'feel' at lower speeds with the Speed Proportional Feel system, it is anticipated that the designer's aim in producing the system would be more fully realized.

4.5.5 DISCUSSION OF THE RESULTS OF THE DISCRIMINANT ANALYSES IN RELATION TO THE FINDINGS OF PREVIOUS RESEARCH.

Before leaving this discussion of the results of the discriminant analyses, reference should be made to the findings of previous research which were reviewed in the Introduction. The results of the discriminant analyses will first be discussed in relation to previous work on the effects of steering characteristics on drivers' performance, and secondly in relation to the work reviewed which employed steering reversals as a measure of drivers' performance.

It was noted in the Introduction that very little formal research has been conducted on the effects of steering characteristics and driver performance. Whilst there have been numerous studies in the general area of vehicle handling which have included the driver 'in the loop', very few studies were found which concerned themselves with vehicle steering characteristics per se, and fewer still which directly addressed questions of relevance to the present work.

Of those studies reviewed, only two, Hoffman and Joubert (1966) and Segel (1964), discussed the effects of power steering force characteristics on drivers' performance. The first of these studies was primarily concerned with the effects of steering ratio, although the authors also noted that gross changes in steering force levels did not affect drivers' performance in a simple turning manouevre. The second study was directly concerned with the effects of the force characteristics of power steering on drivers' performance, but was limited in scope, and consequently rather tentative in its conclusions. In neither of these studies, however, were qualitatively different power steering characteristics employed, or was drivers' performance evaluated in anything but highly specific and rather artificial driving tasks.

Hoffman and Joubert (1966) found no differences in the number of cones hit by subjects who drove a circular course at a speed of 8 m/s when the power steering was 'on' and when it was 'off', despite the fact that this represented a five-fold increase in steering torque. In the present study, the number of cones hit by subjects on the test-track was found to contribute to the ability to discriminate between both males and females and between groups of subjects allocated to different power steering systems. It should be remembered, however, that the number of cones hit by subjects was only one of a number of composite variables which were combined to provide significant discriminant functions. The univariate 'F' ratios reported prior to each discriminant analysis indicate that significant differences existed in the number of cones hit by male and female drivers on both test-track sessions, but that there were no significant differences between the power steering groups in terms of the 'cones' variable. It would seem that when considered on its own, the number of cones hit by drivers may be sensitive to differences in performance due to driver variables such as sex, but not vehicle variables such as power steering.

There are two further points to be considered in a comparison of Hoffman and Joubert's findings and the results of the discriminant analyses reported here, and these concern the nature of the changes to the steering characteristics employed and the nature of the tasks performed by subjects.

The differences in steering torque produced by disconnecting the power assistance in Hoffman and Joubert's study were far greater than the differences in steering torque exhibited by the experimental power steering system in the present study. From this point of view, it might be considered unlikely that the relatively subtle differences between the steering characteristics in the present study would affect drivers' performance sufficiently to be reflected in the number of cones hit. On the other hand, however, the subject's test-track driving task in the present study was far more complex than that used by Hoffman and Joubert, and was carried out at higher speeds, which would suggest that the number of cones hit by subjects might have been a more appropriate measure of performance in the present work. It would appear, therefore, that the number of cones hit by subjects in a test-track driving task is not very sensitive to subtle or gross changes in power steering characteristics if used alone, but may be of use in combination with other variables.

Segel (1964) relied upon drivers' subjective ratings of vehicle handling in assessing the effects of steering force gradient on the ease with which drivers were able to carry out a steady-state turn and a fast lane-change manoeuvre. The results of Segel's study were not subjected to statistical analysis, and his conclusions must be treated with caution, therefore.

Two of Segel's findings are of relevance to the results of the discriminant analyses discussed previously, and these are the driver's tendency to overshoot or undershoot the desired path when the steering force gradient is "too light", and the driver's difficulty in defining the straight ahead position when the force gradient is lower than optimum. The tendency to 'oversteer' and the difficulty associated with judging the straight ahead position were both prominent variables in males' questionnaire responses to the standard power steering system in the first half of the present experiment. Segel's findings suggest, therefore, that male drivers' initial reaction to the standard power steering system in the present study may have been due to an excessively low force gradient. This explanation of males' reaction to the standard power steering is intuitively appealing, since a low force gradient as defined by Segel corresponds very closely to the 'lack of feel' concept described in the Introduction. That is to say, when only a small increase in steering torque is required to produce a large increase in the concerning forces generated at the front wheel, a low force gradient as defined by Segel is implied, and the steering is also said to have little 'feel'. Although the force characteristics of the standard power steering used in the present study were described in terms of hand wheel torque versus system pressure, and Segel defines steering force gradient in terms of steering torque per unit lateral acceleration, if the force characteristics of the typical power steering system shown in Figure 1 were also expressed in terms of steering torque per unit lateral acceleration, a low, almost constant, force gradient would be obtained.

The importance of an optimum force gradient, or steering 'feel' should not be overestimated, however, since, as Segel points out, his subjects were still able to perform their steering tasks adequately in the absence of any force feedback or 'feel'. In addition, the subjects in Segel's study were all male, and the results of the discriminant analyses reported previously suggest that female drivers do not respond in the same way to the force feedback characteristics of the steering. Whereas male drivers tended to 'oversteer' on the first road-run, therefore, females found the standard power steering "sensitive, responsive and with good 'feel'". Moreover, the fact that the variables associated with steering 'feel' were much less prominent in the results of the discriminant analyses carried out on Road-run 2 data, shows that it was not possible to discriminate between male and female drivers on the basis of their response to the force feedback characteristics of the steering in the second half of the experiment. The negative reaction of male drivers to the standard power steering which was attributed to a low force gradient may, therefore, be a temporary phenomenon which disappears as drivers become accustomed to power steering.

Before leaving the topic of steering 'feel', reference should be made to the results of the discriminant analyses in respect of the suggestion made in the Introduction that there is a threshold below which drivers cannot detect changes in steering loads.

Curtis (1972) has argued that, because the steering loads associated with power assisted steering are excessively low, drivers are unable to detect a further lightening of the steering which normally occurs when the front tyres begin to loose their grip. It was suggested, therefore, that the Load Spring characteristics of the experimental steering system would provide a means of examining this 'threshold' hypothesis, since these simply increase steering loads throughout the range of operation of the steering without affecting its other characteristics.

Whilst the results of Discriminant Analysis 16 indicate that drivers were aware of an increase in steering loads associated with the Load Spring systems, in that these were associated with being "too heavy" and "different", there is no evidence to suggest that either the Load Spring Heavy or the Load Spring Light characteristics were considered to provide more steering 'feel' in comparison with the standard power steering. The absence of NFactors which refer to the force feedback characteristics of the steering, therefore, suggests that a simple increase in steering loads does not increase the drivers' awareness of the 'feel' characteristics of power assisted steering.

A number of studies were reviewed in the Introduction in which steering reversals were employed as a measure of driving performance. Although none of these studies was concerned specifically with the effects of steering characteristics on drivers' performance, their findings indicate that steering reversals are sensitive to the effects of driver and task variables in a number of driving situations.

Thus, in a series of papers by Greenshields and Platt, and more recently in Greensmith (1981), it was shown that subjects' control use, including the number of steering reversals, could be used to discriminate between groups of drivers with different accident and violation records. Greensmith also noted that females made more fine steering reversals than males, a finding which is confirmed by the results of the present study. Johns and Bundy (1974) found that drivers' reversals rates remained relatively constant over time, but that their coarse steering reversal rates varied with respect to the types of road over which they drove. Similarly, Soliday and Allen (1972) noted differences in the number of steering reversals made by drivers who were accustomed to power steering and drivers who were accustomed to manual steering. Finally, in a review of previous work, Maclean and Hoffman (1975) concluded that steering reversals reflect the difficulty of the steering task both in terms of the nature of the task itself, and in terms of the level of error tolerated by the driver. In the present study, steering reversals data were found to be useful in characterizing drivers' performance on the road and on the test-track, and featured prominently in the functions used to discriminate between male and female drivers and between power steering groups.

A relationship which emerged in the present study, but was apparently not detected in previous work, is that between steering reversals and driving speed under normal driving conditions on the road. It is clear from the results of the principal components analyses carried out on the data from Road-run 1 and Road-run 2, that there is an implicit negative relationship between the number of fine and coarse steering reversals made by drivers and the speed at which they drove on the road. That is to say, many of the NFactors were defined in terms of the variables Time, Coarse Steer and Fine Steer over specific sections of the route, each having a large, positive factor loading. Long driving times (slow speeds) were, therefore, associated with large numbers of coarse and fine steering reversals. This was not the case with the NFactors derived from the test-track data, however, in which the variables Time, Coarse Steer and Fine Steer tended to appear independently of one another. In discriminating between groups of drivers on the basis of these NFactors, it should be noted, however, that subjects who drove quickly also made relatively few steering reversals (males) and those who drove slowly also made relative more steering reversals (females). There are two likely explanations for the relationship between speed and steering reversals in the findings of the present study.

As noted in the Introduction, the amount of cornering force generated at the front wheels of a car for a given front wheel angle tends to increase with speed, although this relationship becomes non-linear at high levels of lateral acceleration. Consequently, within the range of normal on-the-road driving conditions, the driver is required to make smaller steering wheel displacements to achieve the same change in vehicle heading as his speed increases. If the steering wheel displacements made in steering the car at speed are sufficiently small, therefore, fewer coarse steering reversals and, to a lesser extent, fine steering reversals will be made. Although a reduction in the number of steering reversals might be expected when driving at speed on the roads, on the test-track, where relatively large wheel displacements were necessary to steer the car, the smaller displacements made by those who drove at speed would still be sufficiently large to register as a reversal.

Alternatively, it might be argued that those subjects who drove at speed were, for some reason, also able to steer more skill-fully, or at least more economically, and to make fewer reversals. This explanation is less appealing than the first, however, since it ignores the implicit relationship between cornering forces and speed described above, and makes an assumption about a relationship between the driver's desire to drive at speed and his steering ability for which no evidence has been presented.

MacLean and Hoffman's suggestion that steering reversals provide a measure of steering task difficulty is of interest in the light of the differences in males' and females' test-track performance. In both test-track sessions, males drove faster than females, made fewer steering reversals and hit fewer marker cones. It seems not unreasonable, therefore, to accept MacLean and Hoffman's interpretation of steering reversals as a measure of task difficulty and to assume that females found the test-track driving task more difficult than males did. Although MacLean and Hoffman also suggest that 'steering task difficulty' comprises two components, namely features of the task itself and the tolerance of error on the part of the subject, there is no reason to suppose that females' relatively high numbers of steering reversals were due to their being less tolerant of error. Indeed, in view of the greater number of marker cones hit by female subjects, it might be argued that they were more tolerant of positioning error on the test-track than males.

The interpretation of steering reversals as a measure of steer-ing task difficulty will be further discussed in relation to the findings of the analyses of variance and analyses of covariance of the test-track data in the next section.

4.5.6 ANALYSES OF VARIANCE AND ANALYSES OF COVARIANCE OF THE TEST-TRACK DATA.

The primary purpose of performing the analyses of variance on the data from both test-track sessions was to investigate the validity of the subsidiary task as a measure of 'spare mental capacity'. The major concern, therefore, was to discover whether the presence of the subsidiary task affected the primary task measures of Time, Fine Steer and Coarse Steer.

In addition, however, the results of the analyses of variance also provided information concerning drivers' test-track performance which was of interest in its own right and which, in some cases, provided support for the findings of the discriminant analyses discussed previously. The results of the six analyses of variance performed on the primary task measures from the test-track, and two analyses performed on the subsidiary task scores, are summarized in Table 71.

The results of Analyses of Variance 1 and 4 indicated that males drove faster than females on both test-track sessions. Besides confirming the earlier findings of Discriminant Analyses 3, 4 and 8, the estimated strength of association between subjects' sex and driving speed, est.ω^2 = .09 and est.ω^2 = .11 respectively, indicates that an average of approximately 10% of the variance in drivers' speed was accounted for by their sex. The prominence of the 'Time' NFactors in the discriminant analyses referred to above suggested that drivers' speed on the test-track was the single most important variable in discriminating between males and females, and the results of Analyses of Variance 1 and 4 confirm this.

In a similar way, the NFactors associated with fine steering and coarse steering reversals carried relatively small discriminant weights in the discriminant analyses discussed above, and in general males' and females' steering behaviour was not found to differ in the analyses of variance of test-track data. The only exception to this was the significant Sex effect from Analysis of Variance 6 which suggested that males made more coarse steering reversals than females on the second test-track session. The effect was very weak, however, est.ω^2 = .04, and the presence of a Power by Sex interaction in

TABLE 71 Summary of the results of the analyses of variance conducted on the test-track data showing the source of data, dependent variable, significant effects and associated values of p and est.ω^2

Analysis	Source of Data	Dependent Variable	Significant Effects	p	est ω^2
Anova 1	Test-track 1	Time	Sex	$<.01$	.09
			Order	$<.01$	.56
			Task	$<.01$	.12
			Ord x Task	$<.01$	.28
Anova 2	Test-track 1	Fine Steer	Order	$<.01$	.48
			Task	$<.01$	.47
			Sex x Ord	$<.05$	.01
Anova 3	Test-track 1	Coarse Steer	Order	$<.01$	.37
			Task	$<.01$	.12
			Sex x Task	$<.05$	.03
			Ord x Task	$<.01$	.07
Anova 4	Test-track 2	Time	Sex	$<.01$	.11
			Order	$<.01$	.36
			Task	$<.01$	.33
			Ord x Task	$<.01$	.18
Anova 5	Test-track 2	Fine Steer	Order	$<.01$	.12
			Task	$<.01$	.61
			Ord x Task	$<.05$	.03
Anova 6	Test-track 2	Coarse Steer	Sex	$<.05$	.04
			Order	$<.01$	.06
			Task	$<.01$	.37
			Pow x Sex	$<.05$	.06
Anova*	Test-track 1	Subsidiary Task Scores	Task	$<.01$	.75
Anova*	Test-track 2	Subsidiary Task Scores	Order	$<.01$	.03
			Task	$<.01$	.79
			Pow x Sex	$<.05$	.06
			Ord x Task	$<.01$	.03
			PowxSexxTask	$<.05$	.01

*These analyses were performed on the subsidiary task scores for the purpose of comparison with the analyses of covariance discussed later in this section.

this analysis indicated that the effect was primarily due to subjects' performance with the Conventional Reaction system. Individual comparisons of the Power by Sex interaction means revealed that males made significantly more coarse steering reversals than females only when using the Conventional Reaction system.

The significant Order effects found for all three dependent variables in both test-track sessions can be attributed to subjects' learning or increased familiarity with the test-track driving task. (It should be remembered that level 1 of Order comprised test-track trials 1 and 2, level 2 comprised trials 3 and 4 and so on to level 4 of Order which comprised trials 7 and 8). Thus, the effect of Order was to reduce subjects' driving time and the number of fine and coarse steering reversals made on later trials. Interestingly, although the Order effect was seen in both test-track sessions, the strength of the effect was reduced in the second test-track session as can be seen from the values of est.ω^2 given in Table 71.

The presence of an Order by Task interaction in Analyses of Variance 1, 3, 4, and 5 is important since it indicates that the presence of the subsidiary task tended to reduce the learning effect described above. That is to say, the reduction seen in subjects' driving time, fine steering and coarse steering reversals as they become more familiar with the test-track driving task was much less marked on those trials on which the subsidiary task was performed.

The significant, and generally powerful, Task effects seen in all of the analyses of variance performed on the test-track data are of major importance since they are directly relevant to the first of the questions posed in the Results section, namely "does the presence of the subsidiary task affect subjects' primary task performance?" The answer to this question must be an unequivocal "yes" since each of the primary task measures Time, Fine Steer, and Coarse Steer was found to be significantly different under Task 1 (no subsidiary task) and Task 2 (subsidiary task) conditions. The effect of the subsidiary task was to increase subjects' driving time and the numbers of fine and coarse steering reversals made. In Analysis of Variance 3, a significant but weak Sex by Task interaction indicated that it was only males who showed an increase in the number of coarse steering reversals under subsidiary task conditions during the first test-track session.

Interest in the analyses of covariance performed on subsidiary task scores from both test-track sessions focusses on their ability to remove the effects of the relationship between the primary task measures and the secondary task which was identified in the analyses of variance. The general result of adjusting subsidiary task responses for the effects of the covariates Time, Fine Steer and Coarse Steer was one of reducing the strength of the Task effect and increasing the strength of the Order effect when compared with the appropriate analysis of variance carried out on the unadjusted subsidiary task scores. The results of the two analyses of variance conducted on the unadjusted subsidiary task scores from test-track 1 and test-track 2 are summarized at the bottom of Table 71. The results of the eight analyses of covariance conducted on the subsidiary task data are summarized in Table 72.

In discussing the results of the analysis of variance and analysis of covariance of subsidiary task data, attention should first be drawn to the inevitability of a powerful Task effect, due of course to the complete dependence of subsidiary task responses on whether or not the subsidiary task was administered. The absence of any subsidiary task responses under Task 1 conditions and the presence of subsidiary task responses under Task 2 conditions naturally leadsto a large, rather meaningless, Task effect in the two analyses of variance performed on the subsidiary task data. The strength of this Task effect was reduced in the analyses of covariance, however, when subsidiary task scores were adjusted for the relationship between the subsidiary task and the primary task measures and the latter were used as covariates. This was reflected by the appearance of non-zero means under Task 1 (no

TABLE 72. Summary of results of the analyses of covariance conducted on the test-track data showing the source of data, dependent variable, covariate(s), significant effects and associated values of p and est.ω^2

Analysis	Source of Data	Dependent Variable	Covariate	Significant Effects	p	est ω^2
Anocov 1	Test-track 1	Subsidiary task scores	Time	Order Task	<.01 <.01	.13 .68
Anocov 2	Test-track 1	Subsidiary task scores	Fine Steer	Order Task	<.01 <.01	.05 .42
Anocov 3	Test-track 1	Subsidiary task scores	Coarse Steer	Task	<.01	.70
Anocov 4	Test-track 1	Subsidiary task scores	Time Fine Steer Coarse Steer	Order Task PowxTask	<.01 <.01 <.05	.12 .42 .02
Anocov 5	Test-track 2	Subsidiary task scores	Time	Order Task OrdxTask	<.01 <.01 <.01	.08 .65 .06
Anocov 6	Test-track 2	Subsidiary task scores	Fine Steer	Order Task OrdxTask PowxSexxTask	<.01 <.01 <.01 <.05	.07 .42 .03 .04
Anocov 7	Test-track 2	Subsidiary task scores	Coarse Steer	Order Task OrdxTask	<.01 <.01 <.01	.05 .66 .03
Anocov 8	Test-track 2	Subsidiary task scores	Time Fine Steer Coarse Steer	Order Task OrdxTask	<.01 <.01 <.01	.09 .37 .03

subsidiary task) conditions in the tables associated with the analyses of covariance reported in the Results section. Again, the presence of a Task effect in the analyses of covariance is rather meaningless since it indicates only that there were significantly more subsidiary task responses when the subsidiary task was administered. The fact that the strength of the Task effect was reduced, however, by comparison with the analysis of variance carried out on the unadjusted subsidiary task scores, reflects the previously noted relationship between the presence of the subsidiary and longer driving times and greater numbers of steering reversals on the test-track.

In seven of the eight analyses of covariance, a rather weak Order effect was seen, and in the analyses of the data from Test-track 2, a weak Order by Task interaction was also present. In general, the effect of Order was one of an increasing number of subsidiary task responses on later test-track trials, and, in the case of Analyses of Covariance 5, 6, 7 and 8, the Order by Task interaction means indicated that only under Task 2 (subsidiary task) conditions was the Order effect seen. A significant Order by Task interaction might have been expected in every analysis in which an Order effect was found, since any differences in Order means would automatically be assumed to be limited to Task 2 (subsidiary task) conditions, and not to be present under Task 1 conditions in which the subsidiary task was absent. It would seem, therefore, that the adjustment made for the covariates in the analyses of Test-track 1 data was sufficiently large for there to be significant differences among Task 1 subsidiary task means, and for an Order effect to be associated with both levels of Task, hence the absence of any Order by Task interaction in these analyses.

Although weak, the presence of an Order or an Order by task effect in the analyses of covariance provides some evidence that subjects found that the primary task became less demanding as their familiarity with it increased. Besides responding more frequently to the subsidiary task as the test-track sessions progressed, it should be remembered that subjects also tended to drive faster and make fewer steering rdversals (see the discussion of the analyses of variance of primary task variables above). Neither result is entirely unexpected, however. Indeed, it would be rather surprising if no learning of such a novel task as test-track driving had not taken place.

The only significant effects involving the independent variable of primary interest, namely, power steering, were the Power by Task interaction from Analysis of Covariance 4, and the Power by Sex by Task interaction from Analysis of Covariance 6. As noted in the Results section, however, the Power by Task interaction from Analysis of Covariance 4 was anomolous, in that subjects had been assigned to their power steering groups but were all driving with the standard power steering during the first test-track session from which the data were taken. It was suggested, therefore, that the significant Power by Task interaction was due to a predisposition on the part of some subject groups to respond more frequently to the subsidiary task rather than to any effect attributable to the power steering. It is quite possible, therefore, that the Power by Task by Sex interaction reported in Analysis of Covariance 6 was also the result of a predisposition of subjects in some groups to respond differentially to the subsidiary task rather than to a genuine experimental effect.

It is clear from the results of the analyses of variance discussed above that subjects' performance on the test-track was affectdd by the presence of the subsidiary task. Although instructed to respond to the subsidiary task only when they felt they had time, and to treat the subsidiary task as of secondary importance to the primary task of driving quickly and accurately on the test-track, subjects tended to drive more slowly and to make more steering reversals when responding to the subsidiary task. Moreover, the tendency for subjects to drive more quickly and to make fewer steering reversals as they became more familiar with the test-track driving task, was much less marked on those trials on which the subsidiary task was administered.

The use of analysis of covariance to introduce an 'after the fact' statistical control for the effect of the subsidiary task on subjects' primary task performance was successful, therefore, in as much that the Task effects and Order effects found in the analysis of variance of unadjusted subsidiary task responses were respectively weakened and strengthened when adjustment was made for the covariates. Although the significant Order effect found in the analyses of covariance indicated that subjects found the driving task less demanding as their familiarity with it increased, no reliable effects on subjects' subsidiary task performance were found with respect to the type of power steering in use.

4.5.7 DISCUSSION OF THE RESULTS OF THE ANALYSES OF VARIANCE AND ANALYSES OF COVARIANCE IN RELATION TO THE FINDINGS OF PREVIOUS RESEARCH.

Before leaving this discussion of the results of the analyses of variance and analyses of covariance, reference should be made to the findings of previous research which were reviewed in the Introduction. The results of the analyses of variance and analyses of covariance will first be discussed in relation to previous work which employed steering reversals as a measure of drivers' performance, and secondly in relation to the work reviewed on the use of subsidiary tasks as a measure of 'spare mental capacity'.

Previous research which has employed steering reversals as a measure of driver performance was discussed in the preceding section in the context of the findings of the discriminant analyses. A further point remains to be made, however, with respect to the findings of the analyses of variance conducted on the test-track data and MacLean and Hoffman's conception of steering reversals as a measure of 'steering task difficulty'.

It was argued that the results of the discriminant analyses discussed previously could be interpreted as indicating that females found the test-track driving task more difficult than males, in that females were associated with driving more slowly, hitting more cones, and making greater numbers of steering reversals than males. Whilst the results of the analyses of variance confirmed that males drove faster than females during both test-track sessions, in only one case, Analysis of Variance 6, was a significant difference found between the number of steering reversals made by males and females. Furthermore, this significant difference was in the direction of a higher number of coarse steering reversals made by male drivers, and was confined to the Conventional Reaction steering group. Although the particular combinations of test-track variables used as discriminant functions indicate that females found the test-track driving task more difficult than males, therefore, it is not possible to draw the same conclusion on the basis of the steering reversals data alone.

It was also argued in the previous section that the presence of significant Order effects in both the analyses of variance and analyses of covariance of test-track data indicated that subjects found the test-track driving task less difficult as their familiarity with it increased. Thus, subjects tended to drive faster, to make more subsidiary task responses and fewer steering reversals on successive test-track trials. Whereas the increases in driving speed and the number of subsidiary task responses seem to indicate that subjects found the test-track task less demanding as the sessions progressed, the reduction in the number of steering reversals made may be a direct consequence of the increase in speed or, in the light of MacLean and Hoffman's conclusions, a further indication of a reduction in steering task difficulty over time. Whether the decrease in steering reversals is interpreted as a direct result of the increase in driver's speed as suggested previously, or as an independent measure of steering task difficulty, however, the overall interpretation of the Order effects remains the same.

The use of subsidiary tasks as a measure of 'spare mental capacity' in previous research was reviewed in the Introduction. It was emphasised in the review that, for subsidiary task performance to be interpreted as a valid measure of 'spare mental capacity', the presence of the subsidiary task must be shown not to affect subjects' performance on the primary task.

The results of the analyses of variance conducted on the test-track data indicated quite clearly that, despite their instructions to respond to the subsidiary task only when they felt they had time, subjects made a considerable effort to respond to the subsidiary task to the detriment of their primary task performance. Thus, subjects drove more slowly and made greater numbers of steering reversals on those trials on which the subsidiary task was administered than they did when they were not required to respond to the subsidiary task.

From those studies reviewed, and on the basis of the findings of the present work, it would seem to be very difficult to devise a subsidiary task which is treated as such by subjects, and which fulfils the requirement that it does not interfere with primary task performance. It is possible that the choice of a visual-verbal subsidiary task in the present study was inappropriate, in the sense that both the ability to perform the subsidiary task and the ability to perform the primary task demanded visual information. Some authors, for example, Brown (1978) have argued that subsidiary and primary tasks should not share the same sensory or response modalities. However, as Wetherell (1981) has pointed out, if it is intended to measure drivers' redundant capacity for the driving task, then it seems appropriate to use a subsidiary task which has the most face validity for the situation being studied, that is, a visual and sensory-motor task. In this case, a visual monitoring subsidiary task was chosen for its obvious relevance to activities normally carried out in driving. In retrospect, perhaps a motor response to the visual stimulus may have been preferable to a verbal response in the present study.

Having found that the subsidiary task used in the present study did affect drivers' primary task performance, an attempt was made to statistically compensate for this interference by the use of the analysis of covariance. To the extent that the pattern of subsidiary task scores was different after adjustment for the relationship between primary and subsidiary tasks, the use of the analysis of covariance in this situation can be said to have been successful. It should be remembered, however, that the nature of the relationship between variate and covariate in the analysis of covariance is assumed to be linear, and, in so far that the true nature of the relationship is linear, the technique will be successful in compensating for the effects of the subsidiary task on primary task performance. In the event that the relationship is non-linear, however, the use of the analysis of covariance will be relatively less successful in completely removing the effects of subsidiary task interference on primary task performance.

Fortunately, in the present study the subsidiary task was included as an additional source of data rather than as the only indication of subjects' test-track performance. Whilst an attempt has been made to compensate for the observed relationship between the subsidiary and primary tasks, and to adhere to the interpretation of subsidiary task data as a measure of 'spare mental capacity', therefore, such an interpretation is not essential to an understanding of the test-track data. Given that the reduction in subjects' driving time and the number of steering reversals made on successive trials has been interpreted as an indication that drivers found the test-track task less difficult as they became more familiar with it, therefore it seems reasonable to assume that the increased number of subsidiary task responses may also be interpreted in the same way.

Three points emerge from this discussion of the use of a subsidiary task in research of this kind. The first is that it is very difficult to introduce a subsidiary task into an experiment without affecting subjects' performance on the task of primary interest. The second is that, where the introduction of a subsidiary task has been found to interfere with subjects' primary task performance, a statistical technique such as the analysis of covariance can be used to remove the effects of the subsidiary task/primary task relationship to the extent that this relationship is linear. Finally, as Rolfe (1971) has suggested, subjects' performance on a subsidiary task should be looked upon as a potentially useful source of additional information rather than as a performance measure of primary importance.

4.6. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH.

The research reported here was undertaken to provide an evaluation, by a sample of ordinary drivers, of an experimental multi-characteristic power steering system developed by Cam Gears Ltd. The object of this evaluation was to determine which of the power steering characteristics available in the Cam Gears' system was 'optimal' from the ordinary driver's point of view, and which characteristic would, therefore, be most appropriate for future production systems. The design of the experiment conducted was such that an additional evaluation of drivers' initial responses to the standard power steering characteristics was also possible.

In order to make these evaluations, an initial group of drivers took part in a pilot experiment in which they drove a car fitted with the multi-characteristic power steering system. These drivers were asked to make a running commentary on their reactions to the steering, and their comments were tape recorded. Transcriptions of these tape recordings were then used to devise an evaluation questionnaire.

A further one hundred drivers, half of them males and half of them females, then took part in the major experimental work which involved driving the experimental car over a specified route, completing an evaluation questionnaire, and carrying out various manoeuvres on a test-track. Subjects took part in two identical experimental sessions, the first using the standard power steering system, and in the second session using one of the four experimental systems, (or in the case of a control group of subjects, the standard power steering system again). The same data were collected on both sessions so that, for each subject, two identical sets of information were available, the first set involved subjects' performance with the standard power steering, and the second set their performance with the experimental systems.

The data were then subjected to principal components analysis which provided a series of factors - linear combinations of the original variables - which accounted for most variance in subjects' responses in each of the questionnaires, road drives, and test-track portions of the experiment. These factors were then simplified to make them more interpretable, and were correlated with the original factors to ensure that they correspond closely.

The simplified factors (NFactors) were then used as discriminant variables in another series of analyses which sought to distinguish between groups of subjects. The results of two of these, Discriminant Analyses 4 and 16, best satisfy the requirements and objectives of the study.

Finally, the test-track data were further examined by means of the analysis of variance and analysis of covariance to test the validity of the subsidiary task which was employed during the test-track sessions as a measure of 'spare mental capacity'.

4.6. CONCLUSIONS

Drivers' initial reactions to the standard power assisted steering were clearly shown by the results of Discriminant Analysis 4, which was carried out on the NFactors derived from the data recorded during the first half of the experiment. The results of Discriminant Analysis 4 were discussed in terms of males' and females' responses to the force characteristics of the standard power steering which are depicted in Figure 1. Thus, it was suggested that males, who found it difficult to judge the amount of effort required to steer the car on roundabouts and when making sharp turns, and who tended to 'oversteer', were responding to the non-linear relationship between steering wheel torque and system pressure. In discussing the results of the discriminant analyses in relation to previous work, it was noted that the relationship shown in Figure 1 could also be expressed in terms of Segel's concept of steering force gradient. It was argued that the characteristics of the standard power steering system depicted in Figure 1 would produce a low, almost constant force gradient, so that males' responses provided support for Segel's findings that a low force gradient resulted in drivers undershooting or overshooting the desired path.

As noted in the Introduction, a common criticism of power assisted steering is that it lacks 'feel', that is, its force feedback characteristics are different from those of manual steering systems which tend to produce relatively high force gradients. It is clear from the findings of the present study, however, that the problem of 'lack of feel' is confined to male drivers. Female drivers were not aware of any sudden changes in the effort required to steer the car, on the contrary, they found the steering sensitive, responsive and with good 'feel'.

As Segel points out, the importance of the force feedback characteristics of vehicle steering should not be over-estimated, since his subjects were able to perform their tasks satisfactorily in the absence of any force feedback. Similarly, despite their difficulty in judging the amount of effort required to steer the car under some circumstances, and their tendency to 'oversteer', males in the present study were still willing to manoeuvre the car in traffic.

On the basis of their superior test-track performance, and the relatively lower speed at which they drove in a busy urban area, it was suggested in the Discussion that males may have been driving more safely than females in town during the first road run. Given that they drove faster on the motorway and trunk roads than females, however, it was also suggested that males may have driven less safely than females on the open road. Differences between males' and females' driving patterns in urban and open road driving were less apparent during the second road run, although males continued to drive faster and more accurately on the test-track. From these findings and the work by Storie (1977) referred to previously, there is some evidence that a relationship may exist between males' and females' driving patterns in urban and open road driving and the types of accident in which they become involved.

The specification of the 'optimal' power steering characteristic was made on the basis of the results of Discriminant

Analysis 16. This analysis was carried out on the NFactors derived from the data recorded during the second half of the experiment, and experimental groups were defined in such a way that the subject's sex and the power steering group to which he was allocated were represented. Several problems were noted in the Discussion both in the definition of 'optimal', and with respect to specifying a single characteristic which could be considered 'optimal' for male and female drivers.

Criteria were established, however, whereby those steering systems associated with near zero scores on functions 1 and 2 from Discriminant Analysis 16 could be regarded most favourably. On the basis of these criteria, it is concluded that the Speed Proportional Feel system provided the optimal power steering characteristics for both male and female drivers.

A number of variables were employed to describe drivers' performance in the two test-track sessions, namely, driving time, fine and coarse steering reversals, and the number of marker cones hit by drivers. In addition, a subsidiary task was administered on half of the test-track trials which required subjects to perform a visual-verbal monitoring task. Combinations of these primary task and subsidiary task measures provided an effective means of discriminating between the performance of the experimental groups on the test-track, as indicated by the results of the discriminant analyses.

In addition, a series of analyses of variance and analyses of covariance performed on the test-track data also indicated that subjects found the test-track driving task less demanding as their familiarity with it increased. Thus, subjects tended to drive more quickly and to make fewer steering reversals on successive trials. It was clear from the results of the analyses of variance that the presence of the subsidiary task had affected subjects' primary task performance. In order to introduce an 'after the fact' statistical control for the effects of the subsidiary task on drivers' performance, therefore, a series of analyses of covariance was conducted on the subsidiary task data taking each of the primary task variables as covariates. A weak Order effect was demonstrated in these analyses, with drivers responding more frequently to the subsidiary task on successive trials. The results of the analyses of covariance of subsidiary task data support those of the analyses of primary task measures, therefore, in that drivers appeared to find the task less difficult as their familiarity with it increased. No differences were found between the power steering groups in terms of the number of subsidiary task responses, however, and it is concluded that the various power steering characteristics did not differ with respect to the ease with which they enabled drivers to carry out the test-track driving task.

The efficacy of employing a subsidiary task in research of this nature was questioned in the Discussion due to the difficulty of devising a subsidiary task which is treated as such by subjects. Although the interference of the subsidiary task measure with subjects' primary task performance can, to a greater or lesser extent, be removed by the use of a statistical procedure such as the analysis of covariance, it is concluded that subsidiary tasks should be viewed as an additional source of data and should not be relied upon as the only measure of subjects' performance.

The conclusions which were made on the basis of the results obtained in the present study may be summarized as follows:

1. Whereas male drivers experienced some problems with the standard power steering, finding it difficult to judge the amount of effort required to steer the car under some circumstances and tending to 'oversteer', female drivers were unaware of any sudden changes in the effort required to steer the car, and responded more favourably to the standard power steering. Males' reaction to the standard power steering was thought to be related to its force feedback characteristics, that is, the non-linearities in the handwheel torque/system pressure curve shown in Figure 1. These findings may also be interpreted in terms of Segel's observation that a less than optimal force gradient can result in drivers overshooting or undershooting their desired path.

2. Notwithstanding their comments about the difficulties experienced with the standard power steering, males expressed a willingness to manoeuvre the experimental car in traffic. The importance of the force feedback characteristics of the steering should not be over-estimated, therefore.

3. Males were associated with feeling more confident in the standard power steering at speed, and with driving faster on the open road than females during the first road run. Males were also associated with driving faster and more accurately on the test-track in the first half of the experiement and with driving more slowly in town than females. Whilst this pattern of driving was less marked during the second road run, it was concluded that some evidence exists for a relationship between driving speed and the type of accident in which males and females typically become involved.

4. On the basis of the discriminant functions derived in Discriminant Analysis 16, criteria were developed which allowed one of the experimental characteristics tested to be selected as optimal. The Speed Proportional Feel system was found to best satisfy those critieria for both male and female drivers.

5. Analysis of the primary task and subsidiary task data recorded during the test-track sessions indicated that subjects found the test-track driving task less demanding as their familiarity with it increased. This was reflected in their driving faster, making fewer steering reversals and responding more frequently to the subsidiary task on successive trials.

6. The difficulties associated with the successful implementation of a subsidiary task in research of this nature is such that subsidiary task data should be used to supplement comprehensive primary task measures rather than to provide the only measurement of subjects' performance.

4.6.2. RECOMMENDATIONS FOR FURTHER RESEARCH

Two of the findings from the present study are considered to be worthy of further research. The first of these concerns the differences observed in males' and females' driving speeds in urban and highway driving.

It was noted in the Results section that males drove faster than females on trunk roads and the motorway, but more slowly than females over the largest section of urban driving on the route. It was suggested that males drove less safely than females on the open road, therefore, but more safely than females in town driving (especially in view of males' demonstrated ability to drive quickly and accurately on the test-track). Reference was also made to previous work by Storie (1977) which suggests that males and females are typically involved in different types of accident. (Storie found that males tend to be involved in high speed accidents on the open road, for example, when overtaking, and that females tend to be involved in low speed accidents in urban driving, for example, at road junctions.)

If men and women do differ in terms of the speeds at which they generally drive in urban and open road conditions, and this is related to their accident involvement, it would clearly be of value to determine what factors influence drivers' choice of speed under these conditions. It may well be, for example, that men and women perceive the hazards of driving in town and driving on the open road differently, and that this is reflected in the speed at which they drive, and the type of accident in which they become involved. Further research is needed, therefore, to first confirm that differences exist in males' and females' driving speeds in those situations in which they are more often involved in accidents, and secondly, to indentify the factors which contribute to those differences.

The second finding from the present study which requires further research is entirely concerned with power steering characteristics.

It will be recalled from the Discussion that, in specifying the optimal power steering characteristics for both males and females, the Speed Proportional Feel system was chosen. It was also noted, however, that if male and female drivers were considered separately, the Speed Proportional Feel system appeared most suitable for males, whilst the standard power steering system seemed more suitable for females. Fortunately, this difference really reduces to one of the level of Speed Proportional Feel present in the system, since the latter is superimposed on the characteristics of the standard power steering system. An obvious next step would be to carry out a separate evaluation of the Speed Proportional Feel system in which the level of 'feel' is varied between zero (standard power steering) and a maximum value in excess of that used in the present study.

Whether a single level of Speed Proportional Feel signal could be found which would better suit both males and females is doubtful. The present study would suggest that males might favour a higher level of Speed Proportional Feel than females, but the question would be relatively easily answered empirically.

4.6.3. POST SCRIPT

The results of this study were made available to the Ford Motor Company and to Cam Gears Ltd., immediately they became available and prior to the preparation of this thesis. A modified version of the Speed Proportional Feel system has now been fitted as standard equipment on the 1982 Ford Granada.

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The evaluation of drivers' responses to a multi-characteristic power assisted steering system.

Volume 2 (Appendices)

Supervisor: W T Wilson

June 1982

APPENDIX A. Example of a power steering appraisal form used by one manufacturer's test personnel.

POWER STEERING APPRAISAL SHEET

DRIVER: ____________ DATE: ____________

Vehicle Type: ____________ Engine Size/Type: ____________

Vehicle Registration: ____________ Steering Gear: ____________

Pump: ____________ Hoses: ____________

Cooler: ____________ Tyres: ____________

Modifications:

	Rating: (Ref Below)	Remarks
General Steering Feel	______	____________
Steering Effort - Dry Parking	______	____________
- Driving	______	____________
Steering Response - Straight Line	______	____________
- Cornering	______	____________
Steering Self-Centering (Returnability)	______	____________
Wheel Fight	______	____________
Nibble (Shimmy)	______	____________
Noise (Power Steering)	______	____________

Other comments:

Note: Ratings of 6 or below should be justified.

Rating System:

<table>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td rowspan="2">5
Border Line</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td></tr>
<tr><td colspan="4">Unacceptable</td><td colspan="5">Acceptable</td></tr>
</table>

<table>
<tr><td colspan="2">Production Reject</td><td rowspan="2">Border-Line</td><td rowspan="2">Barely Accep-table</td><td rowspan="2">Fair</td><td rowspan="2">Good</td><td rowspan="2">Very Good</td><td rowspan="2">Excellent</td></tr>
<tr><td>Poor</td><td>Customer Complaint</td></tr>
</table>

APPENDIX B. Form 'A' of the assessment questionnaire.

DRIVER QUESTIONNAIRE NAME ______________________________ FORM A

Please answer the following questions by comparing the car you presently drive with a car you have driven in the past. If you drive more than one car on a regular basis, simply choose one with which you are very familiar. Indicate below which cars you will be comparing.

My "present car" is

Make_______________ Model_________________ Engine Size_________________

My "previous car" is

Make _______________ Model_________________ Engine Size_________________

Please answer ALL the questions, placing a circle around whichever point on the scale seems to fit your own opinion most closely. If a particular item does not apply to the cars which you are comparing, simply circle the middle or "in between" category.

APPENDIX B cont'd.

1. How different is the steering on your present car from the steering on your previous car?

A lot different	slightly different	no different

2. Compared to your previous car, how quickly does your present car respond to the steering when you turn the wheel?

Much more quickly	more quickly	no more quickly	more slowly	much more slowly

3. Compared with your previous car, how sensitive is the steering on your present car with the wheel in the 'straight ahead' position?

Much more sensitive	more sensitive	no more sensitive	less sensitive	much less sensitive

4. How powerful is your present car compared with your previous car?

Much more powerful	more powerful	no more powerful	less powerful	much less powerful

5. Compared with your previous car, how easy was it to get used to the steering on your present car?

Much easier	easier	no easier	more difficult	much more difficult

6. How much 'play' is there in the steering of your present car compared with the steering of your previous car?

Much more play	more play	no more play	less play	much less play

7. Compared with your previous car, how light is the steering of your present car when you are manoeuvring at very low speeds, for example, when parking?

Much lighter	Lighter	no lighter	Heavier	much heavier

8. Having made a sharp turn, how forcefully does the steering wheel return itself to the straight ahead position on your present car, compared with your previous car?

Much more forcefully	more forcefully	no more forcefully	less forcefully	much less forcefully

9. When making a right angle turn in your present car, how difficult is it to position the car accurately compared with your previous car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

APPENDIX B cont'd.

10. How much do you tend to 'oversteer', that is, turn the wheel further than necessary in your present car compared with your previous car?

much more	more	no more	less	much less

11. Compared with your previous car, how difficult is it to judge the amount of effort needed to turn the wheel when making a right angle turn in your present car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

12. When passing a stationary vehicle in your present car, do you tend to move out earlier or later than you did in your previous car?

Much earlier	earlier	no earlier	later	Much later

13. While passing a stationary vehicle in your present car, do you tend to pass any closer alongside the vehicle than you did in your previous car?

Much closer	closer	no closer	less closely	much less closely

14. Having passed a stationary vehicle in your present car, do you tend to return to your lane earlier or later than you did in your previous car?

Much earlier	earlier	no earlier	later	much later

15. When coming up behind a slow moving vehicle, with traffic approaching from the opposite direction, are you more or less likely to squeeze past in your present car than in your previous car?

Much more likely	more likely	no more likely	less likely	much less likely

16. Compared with your previous car, do you tend to 'hold back' more or less often in your present car to allow drivers coming towards you to move into your lane when their lane is blocked?

Much more often	more often	no more often	less often	much less often

17. Would you be more or less likely to steer around a pedestrain in the middle of crossing the croad rather than stopping in your present car compared with your previous car?

Much more likely	more likely	no more likely	less likely	much less likely

APPENDIX B cont'd.

18. Do you find the steering of your present car too light or too heavy at low speeds?

Much too light	too light	not too light	too heavy	much too heavy

19. Compared with your previous car, how much confidence does the steering of your present car give you?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

20. When entering a roundabout, how difficult is it to position your present car accurately compared with your previous car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

21. Compared with your previous car, how light or heavy is the steering of your present car when manoeuvring at very low speeds, for example, when parking?

Much lighter	lighter	no lighter	heavier	much heavier

22. When approaching a line of traffic at traffic lights, are you more or less likely to pass on the outside and form a second line in your present car compared with your previous car?

Much more likely	more likely	no more likely	less likely	much less likely

23. How willing are you to "wait your turn" at a mini roundabout in your present car compared with your previous car?

Much more willing	more willing	no more willing	less willing	much less willing

24. How long does it take you to go round a mini roundabout in your present car compared with your previous car?

Much longer	longer	no longer	less time	much less time

25. How long does it take you to enter a mini roundabout in your present car compared with your previous car?

Much longer	longer	no longer	less time	much less time

26. Compared with your previous car, how difficult is it to judge the amount of effort needed to turn the wheel when you are entering an ordinary roundabout in your present car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

APPENDIX B cont'd.

27. How willing are you to 'nip in and out' to go around a stationary vehicle in your present car compared with your previous car?

Much more willing	more willing	no more willing	less willing	much less willing

28. Compared with your previous car, how easy or difficult is it to keep your present car 'on course' over uneven road surfaces?

Much easier	easier	no easier	more difficult	much more difficult

29. Compared with your previous car, how difficult is it to position your present car accurately when you are driving along straight roads?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

30. How much confidence does your present car's steering give you at moderate speeds compared with your previous car?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

31. Compared with your previous car, how light is the steering on your present car at moderate to high speeds?

Much lighter	lighter	no lighter	heavier	much heavier

32. Do you find that the steering on your present car is too light or too heavy at moderate to high speeds?

Much too light	too light	not too light	too heavy	much too heavy

33. Do you find that the amount of effort required to turn the wheel is greater or less when driving slowly in your present car than when driving fast?

Much greater	greater	no greater	less	much less

34. Compared with your previous car, how much confidence does the steering on your present car give you at high speeds?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

APPENDIX B cont'd.

35. Compared with your previous car, how difficult is it to position your present car accurately on bends?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

36. Compared with your previous car, how difficult is it to judge the amount of effort needed to turn the wheel when taking a sharp bend in your present car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

37. How fast do you drive along straight roads in your present car compared with your previous car?

Much faster	faster	no faster	more slowly	much more slowly

38. Compared with your previous car, how fast do you drive through bends in your present car

Much faster	faster	no faster	more slowly	much more slowly

39. When you are taking a right hand bend in your present car, how likely are you to cross the white line compared with taking a right hand bend in your previous car?

Much more likely	more likely	no more likely	less likely	much less likely

40. Compared with your previous car, do you overtake more or less often in your present car?

Much more often	more often	no more often	less often	much less often

41. Compared with your previous car, does the steering on your present car give you more or less confidence when you are overtaking another vehicle?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

42. Compared with your previous car, how difficult is it to position your present car accurately when changing lanes to pass another vehicle?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

APPENDIX B cont'd.

43. Are you more or less likely to enter small gaps in the traffic in your present car compared with your previous car?

Much more likley	more likely	no more likley	less likely	much less likely

44. Compared with your previous car, have you noticed any more or any fewer sudden changes in the amount or effort required to turn the wheel while steering your present car?

Many more	more	no more	fewer	many fewer

45. How much do you have to think about steering your present car compared with your previous car?

much more	more	no more	less	much less

46. When turning right from a major road into a minor road, are you more or less likely to 'cut the corner' and cross the lane markings on the minor road in your present car compared with your previous car?

Much more likely	more likely	no more likely	less likely	much less likely

47. Do you find that the amount of effort required to turn the wheel in your present car is greater or less when cornering hard than when cornering gently?

Much greater	greater	no greater	less	much less

48. Compared with your previous car, how difficult is it to judge when the front wheels are pointing straight ahead in your present car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

49. Compared with your previous car, how difficult is it to tell in your present car how much grip there is between the front wheels and the road?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

50. On the motorway, how willing are you to accept a smaller gap in the traffic when changing lanes in your present car compared with your previous car?

Much more willing	more willing	no more willing	less willing	much less willing

APPENDIX B cont'd.

51. On the motorway, how difficult is it to control your present car when changing lanes at moderate speeds compared with your previous car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

52. On the motorway how difficult is it to control your present car when changing lanes at high speeds compared with your previous car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

53. On the motorway, how difficult is it to maintain your lane position at moderate speeds in your present car compared with your previous car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

54. On the motorway how difficult is it to maintain your lane position at high speeds in your present car compared with your previous car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

55. Compared with your previous car, how many corrective steering movements do you need to make in your present car

Many more	more	no more	less	many less

56. Compared with your previous car, do you feel that you have more or less to do when driving your present car?

Much more to do	more to do	no more to do	less to do	much less to do

57. If you have more or less to do when driving your present car, is this due to any of the following?

The steering?

Completely due	partly due	not at all due

The type of gearbox ?

Completely due	partly due	not at all due

To the brakes ?

Completely due	partly due	not at all due

APPENDIX B cont'd.

8

58. Compared with your previous car, how fast do you drive on average, in your present car

Much faster	faster	no faster	more slowly	much more slowly

59. How smoothly are you able to drive in your present car compared with your previous car?

Much more smoothly	more smoothly	no more smoothly	less smoothly	much less smoothly

60. Do you feel that the steering on your present car gives you more or less control over the car compared with the steering on your previous car?

Much more	more	no more	less	much less

61. How frustrated do you become driving your present car compared with driving your previous car?

Much more frustrated	more frustrated	no more frustrated	less frustrated	much less frustrated

62. Overall do you find the steering of your present car too light or too heavy?

Much too light	too light	not too light	too heavy	much too heavy

63. Overall do you find the steering of your present car lighter or heavier than the steering of your previous car?

Much lighter	lighter	no lighter	heavier	much heavier

64. Compared with your previous car, do you find that you drive more or less aggressively in your present car?

Much more aggressively	more aggressively	no more aggressively	less aggressively	much less aggressively

65. Compared with your previous car, do you find that you are more or less relaxed in your present car?

Much more relaxed	more relaxed	no more relaxed	less relaxed	much less relaxed

66. Compared with your previous car, how alert are you when driving your present car?

Much more alert	more alert	no more alert	less alert	much less alert

APPENDIX B cont'd.

67. When looking for a parking space in your present car, would you be more or less willing to park on the other side of the road compared with parking in your previous car?

Much more willing	more willing	no more willing	less willing	much less willing

68. Compared with your previous car, do you feel you drive more or less safely in your present car?

Much more safely	more safely	no more safely	less safely	much less safely

69. Do you find the steering on your present car gives you more or less confidence at low speeds than at high speeds?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

APPENDIX B cont'd. Form 'B' of the assessment questionnaire.

DRIVER QUESTIONNAIRE NAME ______________________ FORM B

Please answer the following questions by comparing the car you have just driven with your own car (your 'present car' on Form A of the questionnaire).

Please answer ALL the questions placing a circle round whichever point on the scale seems to fit your own opinion most closely. If a particular item does not apply to the cars which you are comparing, simply circle the middle or "in between" category.

APPENDIX B cont'd.

1. How different is the steering on the car you have just driven from the steering on your own car?

A lot different	slightly different	no different

2. Compared to your own car, how quickly does the car you've just driven respond to the steering when you turn the wheel?

Much more quickly	more quickly	no more quickly	more slowly	much more slowly

3. Compared with your own car, how sensitive was the steering on the car you've just driven with the wheel in the 'straight ahead' position?

Much more sensitive	more sensitive	no more sensitive	less sensitive	much less sensitive

4. How powerful is your own car compared with the car you've just driven?

Much more powerful	more powerful	no more powerful	less powerful	much less powerful

5. Compared with your own car, how easy was it to get used to the steering on the car you've just driven?

Much easier	easier	no easier	more difficult	much more difficult

6. How much 'play' is there in the steering of the car you've just driven compared with the steering of your own car?

Much more play	more play	no more play	less play	much less play

7. Compared with your own car, how light was the steering of the car you've just driven when you are manoeuvring at very low speeds, for example, when parking

Much lighter	lighter	no lighter	heavier	much heavier

8. Having made a sharp turn, how forcefully did the steering wheel return itself to the straight ahead position on the car you've just driven compared with your own car?

Much more forcefully	more forcefully	no more forcefully	less forcefully	much less forcefully

9. When making a right angle turn in the car you've just driven, how difficult was it to position the car accurately compared with your own car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

APPENDIX B cont'd.

10. How much did you tend to 'oversteer' that is, turn the wheel further than necessary, in the car you've just driven compared with your own car?

Much more	more	no more	less	much less

11. Compared with your own car, how difficult is it to judge the amount of effort needed to turn the wheel when making a right angle turn in the car you've just driven?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

12. When passing a stationary vehicle in the car you've just driven, did you tend to move out earlier or later than you do in your own car?

Much earlier	earlier	no earlier	later	much later

13. While passing a stationary vehicle in the car you've just driven, did you tend to pass any closer alongside the vehicle than you do in your own car?

Much closer	closer	no closer	less closely	much less closely

14. Having passed a stationary vehicle in the car you've just driven, did you tend to return to your lane earlier or later than you do in your own car?

Much earlier	earlier	no earlier	later	much later

15. When coming up behind a slow moving vehicle with traffic approaching from the opposite direction, were you more or less likely to squeeze past in the car you've just driven than in your own car?

Much more likely	more likely	no more likely	less likely	much less likely

16. Compared with your own car, did you tend to 'hold back' more or less often in the car you've just driven to allow drivers coming towards you to move into your lane when their lane was blocked?

Much more often	more often	no more often	less often	much less often

17. Would you be more or less likely to steer around a pedestrian in the middle of crossing the road rather than stopping in the car you've just driven compared with your own car?

Much more likely	more likely	no more likely	less likely	much less likely

APPENDIX B cont'd.

18. Do you find the steering of the car you've just driven too light or too heavy at low speeds?

Much too light	too light	not too light	too heavy	much too heavy

19. Compared with yoru own car, how much confidence does the steering of the car you've just driven give you?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

20. When entering a roundabout how difficult was it to position the car you've just driven accurately compared with your own car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

21. Compared with yoru own car, how light or heavy was the steering of the car you've just driven when manoeuvring at very low speeds, for example, when parking?

Much lighter	lighter	no lighter	heavier	much heavier

22. When approaching a line of traffic at traffic lights, were you more or less likely to pass on the outside and form a second lane in the car you've just driven compared with your own car?

Much more likely	more likely	no more likely	less likely	much less likely

23. How willing were you to 'wait your turn' at a mini roundabout in the car you've just driven compared with your own car?

Much more willing	more willing	no more willing	less willing	much less willing

24. How long did it take you to go round a mini roundabout in the car you've just driven compared with your own car?

Much longer	longer	no longer	less time	much less time

25. How long did it take you to enter a mini roundabout in the car you've just driven, compared with your own car?

Much longer	longer	no longer	less time	much less time

26. Compared with your own car, how difficult was it to judge the amount of effort needed to turn the wheel when you are entering an ordinary roundabout in the car you've just driven?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

APPENDIX B cont'd.

27. How willing were you to 'nip in and out' to go around a stationary vehicle in the car you've just driven compared with your own car?

Much more willing	more willing	no more willing	less willing	much less willing

28. Compared with your own car, how easy or difficult was it to keep the car you've just driven 'on course' over uneven road surfaces?

Much easier	easier	no easier	more difficult	much more difficult

29. Compared with your own car, how difficult was it to position accurately the car you've just driven when you were driving along straight roads?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

30. How much confidence did the steering of the car you've just driven give you at moderate speeds compared with your own car

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

31. Compared with your own car, how light is the steering on the car you've just driven at moderate to high speeds?

Much lighter	lighter	no lighter	heavier	much heavier

32. Did you find that the steering on the car you've just driven was too light or too heavy at moderate to high speeds?

Much too light	too light	not too light	too heavy	much too heavy

33. Did you find that the amount of effort required to turn the wheel is greater or less when driving slowly in the car you've just driven than when driving fast?

Much greater	greater	no greater	less	much less

34. Compared with your own car, how much confidence did the steering on the car you've just driven give you at high speeds?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

APPENDIX B cont'd.

35. Compared with your own car how difficult was it to position the car you've just driven accurately on bends?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

36. Compared with your own car how difficult was it to judge the amount of effort needed to turn the wheel when taking a sharp bend in the car you've just driven?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

37. How fast did you drive along straight roads in the car you've just driven compared with your own car?

Much faster	faster	no faster	more slowly	much more slowly

38. Compared with your own car, how fast did you drive through bends in the car you've just driven?

Much faster	faster	no faster	more slowly	much more slowly

39. When you were taking a right hand bend in the car you've just driven, how likely were you to cross the white line compared with taking a right hand bend in your own car?

Much more likely	more likely	no more likely	less likely	much less likely

40. Compared with your own car, did you overtake more or less often in the car you've just driven?

Much more often	more often	no more often	less often	much less often

41. Compared with your own car, did the steering on the car you've just driven give you more or less confidence when you were overtaking another vehicle?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

42. Compared with your own car, how difficult was it to position the car you've just driven accurately when changing lanes to pass another vehicle?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

APPENDIX B cont'd.

43. Were you more or less likely to enter small gaps in the traffic in the car you've just driven compared with your own car?

Much more likely	more likely	no more likely	less likely	much less likely

44. Compared with your own car did you notice any more or any fewer sudden changes in the amount of effort required to turn the wheel in the car you've just driven?

Many more	more	no more	fewer	many fewer

45. How much did you have to think about steering the car you've just driven compared with your own car?

Much more	more	no more	less	much less

46. When turning right from a major road into a minor road, were you more or less likely to 'cut the corner' and cross the lane markings on the minor road in the car you've just driven compared with your own car?

Much more likely	more likely	no more likely	less likely	much less likely

47. Did you find that the amount of effort required to turn the wheel in the car you've just driven was greater or less when cornering hard than when cornering gently?

Much greater	greater	no greater	less	much less

48. Compared with your own car, how difficult was it to judge when the front wheels were pointing straight ahead on the car you've just driven?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

49. Compared with your own car how difficult was it to tell in the car you've just driven how much grip there was between the front wheels and the road?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

50. On the motorway how willing were you to accept a smaller gap in the traffic when changing lanes in the car you've just driven compared with your own car?

Much more willing	more willing	no more willing	less willing	much less willing

51. On the motorway how difficult was it to control the car you've just driven when changing lanes at moderate speeds compared with your own car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

APPENDIX B cont'd.

52. On the motorway how difficult was it to control the car you've just driven when changing lanes at high speeds compared with your own car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

53. On the motorway how difficult was it to maintain your lane position at moderate speeds in the car you've just driven compared with your own car?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

54. On the motorway how difficult was it to maintain your lane position at high speeds in the car you've just driven compared with your own car

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

55. Compared with your own car how many corrective steering movements did you need to make in the car you've just driven?

Many more	more	no more	less	many less

56. Compared with your own car do you feel that you had more or less to do in the car you've just driven

Much more to do	more to do	no more to do	less to do	much less to do

57. If you felt that you had more or less to do in the car you've just driven was this due to any of the following?

The Steering?

Completely due	Partly due	Not at all due

The type of Gearbox?

Completely due	partly due	not at all due

To the brakes?

Completely due	partly due	not at all due

58. Compared with your own car how fast did you drive on average in the car you've just driven?

Much faster	faster	no faster	more slowly	much more slowly

APPENDIX B cont'd.

59. How smoothly were you able to drive in the car you've just driven compared with your own car?

Much more smoothly	more smoothly	no more smoothly	less smoothly	much less smoothly

60. Did you feel that the steering on the car you've just driven gave you more or less control over the car compared with the steering in your own car?

Much more	more	no more	less	much less

61. How frustrated did you become in the car you've just driven compared with driving your own car?

Much more frustrated	more frustrated	no more frustrated	less frustrated	much less frustrated

62. Overall did you find the steering of the car you've just driven too light or too heavy?

Much too light	too light	not too light	too heavy	much too heavy

63. Overall did you find the steering of the car you've just driven lighter or heavier than the steering of your own car?

Much lighter	lighter	no lighter	heavier	much heavier

64. Compared with your own car did you find that you drive more or less aggressively in the car you've just driven

Much more aggressively	more aggressively	no more aggressively	less aggressively	much less aggressively

65. Compared with your own car did you find that you were more or less relaxed in the car you've just driven?

Much more relaxed	more relaxed	no more relaxed	less relaxed	much less relaxed

66. Compared with your own car how alert did you feel in the car you've just driven?

Much more alert	more alert	no more alert	less alert	much less alert

APPENDIX B cont'd.

67. When looking for a parking space in the car you've just driven, would you be more or less willing to park on the other side of the road compared with parking in your own car?

Much more willing	more willing	no more willing	less willing	much less willing

68. Compared with your own car did you feel that you drive more or less safely in your car than the car you've just driven in?

Much more safely	more safely	no more safely	less safely	much less safely

69. Did you find the steering on the car you've just driven gave you more or less confidence at low speeds than at high speeds?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

APPENDIX B cont'd. Form 'C' of the assessment questionnaire.

DRIVER QUESTIONNAIRE. NAME______________________________ FORM C

Please answer the following questions by comparing the car as you have just driven it with the car as it was when you first drove it.

Please answer ALL the questions placing a circle around whichever point on the scale seems to fit your own opinion most closely. If a particular item does not apply, simply circle the middle or "in between" category.

APPENDIX B cont'd.

1. How different was the steering on the car this time from the steering on the car last time?

A lot different	slightly different	no different

2. Compared to the car last time how quickly did the car respond this time to the steering when you turn the wheel?

Much more quickly	more quickly	no more quickly	more slowly	much more slowly

3. Compared with the car last time how sensitive was the steering on the car this time with the wheel in the 'straight ahead' position?

Much more sensitive	more sensitive	no more sensitive	less sensitive	much less sensitive

4. How powerful was the car this time compared with the car last time?

Much more powerful	more powerful	no more powerful	less powerful	much less powerful

5. Compared with the car last time, how easy was it to get used to the steering on the car this time?

Much easier	easier	no easier	more difficult	much more difficult

6. How much play was there in the steering of the car this time compared with the steering of the car last time?

Much more play	more play	no more play	less play	much less play

7. Compared with the car last time how light was the steering of the car this time when you were manoeuvring at very low speeds, for example when parking?

Much lighter	lighter	no lighter	heavier	much heavier

8. Having made a sharp turn how forcefully did the steering wheel return itself to the straight ahead position on the car this time compared with the car last time?

Much more forcefully	more forcefully	no more forcefully	less forcefully	much less forcefully

9. When making a right angle turn in the car this time how difficult was it to position the car accurately compared with the car last time?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

APPENDIX B cont'd.

10. How much did you tend to oversteer that is, turn the wheel further than necessary in the car this time compared with the car last time?

Much more	more	no more	less	much less

11. Compared with the car last time how difficult was it to judge the amount of effort needed to turn the wheel when making a right angle turn in the car this time?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

12. When passing a stationary vehicle in the car this time did you tend to move out earlier or later than you did in the car last time?

Much earlier	earlier	no earlier	later	much later

13. While passing a stationary vehicle in the car this time did you tend to pass any closer alongside the vehicle than you did in the car last time?

Much closer	closer	no closer	less closely	much less closely

14. Having passed a stationary vehicle in the car this time did you tend to return to your lane earlier or later than you did in the car last time?

Much earlier	earlier	no later	later	much later

15. When coming up behind a slow moving vehicle with traffic approaching from the opposite direction were you more or less likely to squeeze past in the car this time than you were in the car last time?

Much more likely	more likely	no more likely	less likely	much less likely

16. Compared with the car last time did you tend to hold back more or less often in the car this time to allow drivers coming towards you to move into your lane when their lane was blocked?

Much more often	more often	no more often	less often	much less often

17. Would you be more or less likely to steer around a pedestrian in the middle of crossing the road rather than stopping in the car this time compared with the car last time?

Much more likely	more likely	no more likely	less likely	much less likely

APPENDIX B cont'd.

18. Do you find the steering of the car this time too light or too heavy at low speeds?

Much too light	too light	not too light	too heavy	much too heavy

19. Compared with the car last time how much confidence does the steering of the car this time give you?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

20. When entering a roundabout how difficult was it to position the car accurately this time compared with the car last time?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

21. Compared with the car last time how light or heavy was the steering of the car this time when manoeuvring at very low speeds, for example, when parking?

Much lighter	lighter	no lighter	heavier	much heavier

22. When approaching a line of traffic at traffic lights were you more or less likely to pass on the outside and form a second lane in the car this time compared with the car last time?

Much more, likely	more likely	no more likely	less likely	much less likely

23. How willing were you to wait your turn at a mini roundabout in the car this time compared with the car last time?

Much more willing	more willing	no more willing	less willing	much less willing

24. How long did it take you to go <u>round</u> a mini roundabout in the car this time compared with the car last time?

Much longer	longer	no longer	less time	much less time.

25. How long did it take you to <u>enter</u> a mini roundabout in the car this time compared with the car last time?

Much longer	longer	no longer	less time	much less time

APPENDIX B cont'd.

26. Compared with the car last time, how difficult was it to judge the amount of effort needed to turn the wheel when you were entering an ordinary roundabout in the car this time?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

27. How willing were you to "nip in and out" to go around a stationary vehicle in the car this time compared with the car last time?

Much more willing	more willing	no more willing	less willing	much less willing

28. Compared with the car last time, how easy or difficult was it to keep the car on course over uneven road surfaces this time?

Much easier	easier	no easier	more difficult	much more difficult

29. Compared with the car last time how difficult was it to position the car accurately this time when you were driving along straight roads?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

30. How much confidence did the steering of the car this time give you at moderate speeds compared with the car last time?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

31. Compared with the car last time how light is the steering on the car this time at moderate to high speeds?

Much lighter	lighter	no lighter	heavier	much heavier

32. Did you find that the steering on the car this time was too light or too heavy at moderate to high speeds?

Much too light	too light	not too light	too heavy	much too heavy

33. Did you find that the amount of effort required to turn the wheel was greater or less when driving slowly in the car this time than when driving fast?

Much greater	greater	no greater	less	much less

APPENDIX B cont'd.

34. Compared with the car last time how much confidence did the steering on the car this time give you at high speeds?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

35. Compared with the car last time how difficult was it to position the car accurately this time on bends?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

36. Compared with the car last time how difficult was it to judge the amount of effort needed to turn the wheel when taking a sharp bend in the car this time?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

37. How fast did you drive along straight roads in the car this time compared with the car last time

Much faster	faster	no faster	more slowly	much more slowly

38. Compared with the car last time how fast did you drive through bends in the car this time?

Much faster	faster	no faster	more slowly	much more slowly

39. When you were taking a right hand bend in the car this time how likely were you to cross the white line compared with taking a right hand bend in the car last time?

Much more likely	more likely	no more likely	less likely	much less likely

40. Compared with the car last time did you overtake more or less often in the car this time?

Much more often	more often	no more often	less often	much less often

41. Compared with the car last time did the steering on the car this time give you more or less confidence when you were overtaking another vehicle?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

APPENDIX B cont'd.

42. Compared with the car last time how difficult was it to position the car accurately this time when changing lanes to pass another vehicle?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

43. Were you more or less likely to enter small gaps in the traffic in the car this time compared with the car last time?

Much more likely	more likely	no more likely	less likely	much less likely

44. Compared with the car last time did you notice any more or any fewer sudden changes in the amount of effort required to turn the wheel in the car this time?

Many more	more	no more	fewer	many fewer

45. How much did you have to think about steering the car this time compared with the car last time?

Much more	more	no more	less	much less

46. When turning right from a major road into a minor road were you more or less likely to cut the corner and cross the lane markings on the minor road in the car this time compared with the car last time?

Much more likely	more likely	no more likely	less likely	much less likely

47. Did you find that the amount of effort required to turn the wheel in the car this time was greater or less when cornering hard than when cornering gently?

Much greater	greater	no greater	less	much less

48. Compared with the car last time how difficult was it to judge when the front wheels were pointing straight ahead on the car this time?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

49. Compared with the car last time how difficult was it to tell this time how much grip there was between the cars front wheels and the road?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

APPENDIX B cont'd.

50. On the motorway, how willing were you to accept a smaller gap in the traffic when changing lanes in the car this time compared with the car last time?

Much more willing	more willing	no more willing	less willing	much less willing

51. On the motorway how difficult was it to control the car this time when changing lanes at moderate speeds compared with the car last time?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

52. On the motorway how difficult was it to control the car this time when changing lanes at high speeds compared with the car last time?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

53. On the motorway how difficult was it to maintain your lane position at moderate speeds in the car this time compared with the car last time?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

54. On the motorway how difficult was it to maintain your lane position at high speeds in the car this time compared with the car last time?

Much more difficult	more difficult	no more difficult	less difficult	much less difficult

55. Compared with the car last time how many corrective steering movements did you need to make in the car this time?

Many more	more	no more	less	many less

56. Compared with the car last time did you feel that you had more or less to do in the car this time?

Much more to do	more to do	no more to do	less to do	much less to do

57. If you felt ath you had more or less to do in the car this time was this due to any of the following:

	Completely due	partly due	not at all due
The steering?			
The type of gearbox?			
To the brakes?			

APPENDIX B cont'd.

58. Compared with the car last time how fast did you drive on average in the car this time?

Much faster	faster	no faster	more slowly	much more slowly

59. How smoothly were you able to drive in the car this time compared with the car last time?

Much more smoothly	more smoothly	no more smoothly	less smoothly	much less smoothly

60. Did you feel that the steering on the car this time gave you more or less control over the car compared with the steering last time?

Much more	more	no more	less	much less

61. How frustrated did you become in the car this time compared with driving the car last time

Much more frustrated	more frustrated	no more frustrated	less frustrated	much less frustrated

62. Overall, did you find the steering of the car this time too light or too heavy?

Much too light	too light	not too light	too heavy	much too heavy

63. Overall, did you find the steering of the car this time lighter or heavier than the steering of the car last time?

Much lighter	lighter	no lighter	heavier	much heavier

64. Compared with the car last time did you find that you drove more or less agressively in the car this time?

Much more aggressively	more aggressively	no more aggressively	less aggressively	much less aggressively

65. Compared with the car last time, did you find that you were more or less relaxed in the car this time?

Much more relaxed	more relaxed	no more relaxed	less relaxed	much less relaxed

APPENDIX B cont'd.

66. Compared with the car last time how alert did you feel in the car this time?

Much more alert	more alert	no more alert	less alert	much less alert

67. When looking for a parking space in the car this time, would you be moreor less willing to park on the other side of the road compared with parking in the car last time?

Much more willing	more willing	no more willing	less willing	much less willing

68. Compared with the car last time did you feel that you drove more or less safely in the car this time?

Much more safely	more safely	no more safely	less safely	much less safely

69. Did you find the steering on the car this time gave you more or less confidence at low speeds than at high speeds?

Much more confidence	more confidence	no more confidence	less confidence	much less confidence

APPENDIX C. Details of subjects' age, driving experience, and experience of power steering and automatic transmission.

	AGE (years)		DRIVING EXPERIENCE (years)		DISTANCE DRIVEN LAST YEAR (x1000 km)		NUMBER WITH EXPERIENCE OF AUTO TRANS.			NUMBER WITH EXPERIENCE OF POWER STEERING		
	Md.	Range	Md.	Range	Md.	Range	None	Some	Much	None	Some	Much
MALES (overall)	29.4	19-60	11.4	1.5-40	18.3	6-90	23	16	11	21	20	9
Load Spring Heavy	27.5	24-48	13.5	6.0-30	19.0	13-90	6	3	1	4	5	1
Load Spring Light	27.0	20-38	9.0	4.0-20	14.5	8-80	3	3	4	2	3	5
Speed Proportional Feel	31.5	19-60	12.0	2.5-40	15.5	6-80	4	3	3	7	1	2
Conventional Reaction	33.5	21-45	13.0	1.5-25	17.5	10-24	5	4	1	6	4	0
Control	23.0	20-42	6.5	2.0-24	17.5	11-19	5	3	2	2	7	1
FEMALES (overall)	29.3	19-58	11.2	1.0-40	18.0	2-64	27	13	10	28	15	7
Load Spring Heavy	31.0	23-50	10.5	1.5-33	7.0	12-20	6	1	3	6	2	2
Load Spring Light	24.5	20-58	6.5	1.0-40	14.5	2-24	4	4	2	6	3	1
Speed Proportional Feel	25.0	20-39	4.5	1.0-22	10.0	2-24	6	4	0	5	5	0
Conventional Reaction	31.0	19-55	10.5	1.5-20	17.0	8-48	5	2	3	5	3	2
Control	28.5	21-48	5.0	2.0-22	10.5	2-19	6	2	2	6	2	2

APPENDIX D. Modifications and additional equipment fitted to the interior of the experimental car.

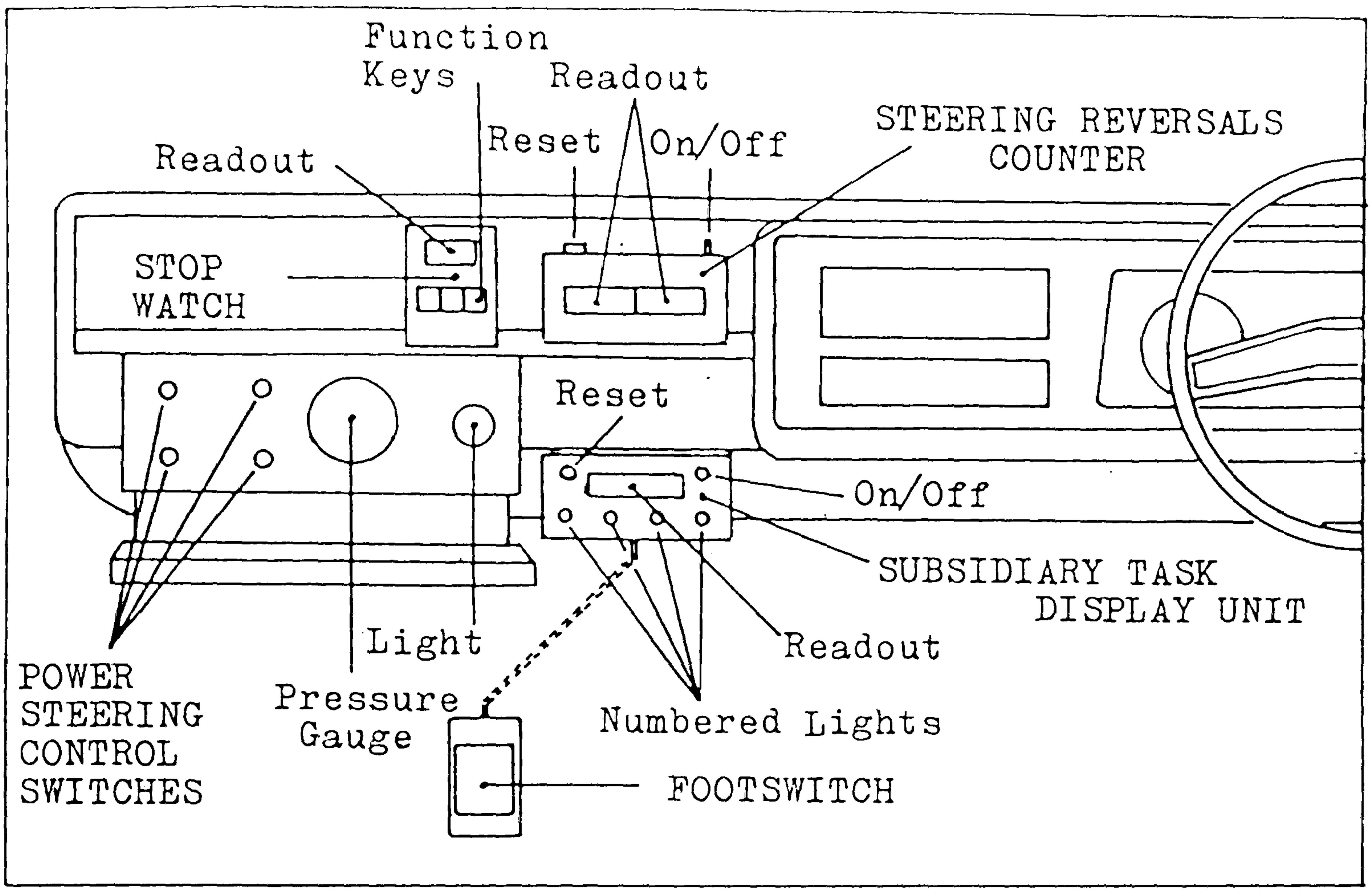


FIGURE 1. Recording instruments and power steering control switches.

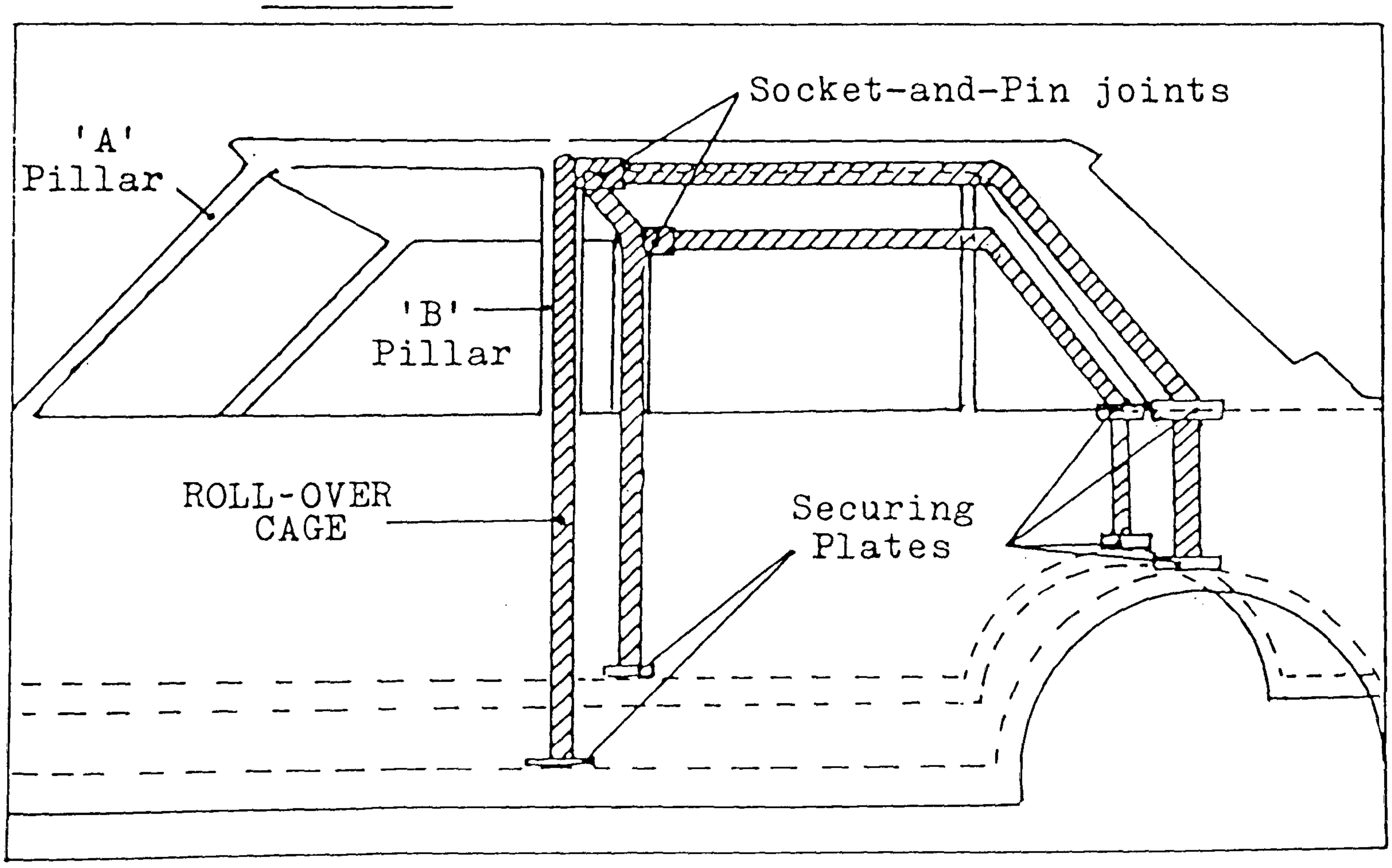


FIGURE 2. The roll-over cage.

APPENDIX E. Data sheet used to record subjects' biographical data.

PROSPECTIVE SUBJECT BIOGRAPHICAL DATA

NAME______________________ SEX__________ AGE__________

ADDRESS____

____

TEL NO.____________________ OCCUPATION______________

DRIVING RECORD:

TYPE OF LICENCE__________________ NO YEARS HELD.__________

APPROX ANNUAL MILEAGE.__________ CAR PRESENTLY OWNED/DRIVEN__________

MAKE__________ MODEL__________ YEAR__________

CARS PREVIOUSLY OWNED/DRIVEN: NONE ______ FEW ______ MANY ______

FAMILIARY WITH AUTO TRANS: NONE ______ LITTLE______ LOT______

FAMILIARY WITH PAS: NONE______ LITTLE .______ LOT ______

ATTITUDES TO DRIVING:

ENJOY IT?____

MOTOR SPORT?____

GIVEN CHOICE WHAT CAR?____

WHY?____

AVAILABILITY:

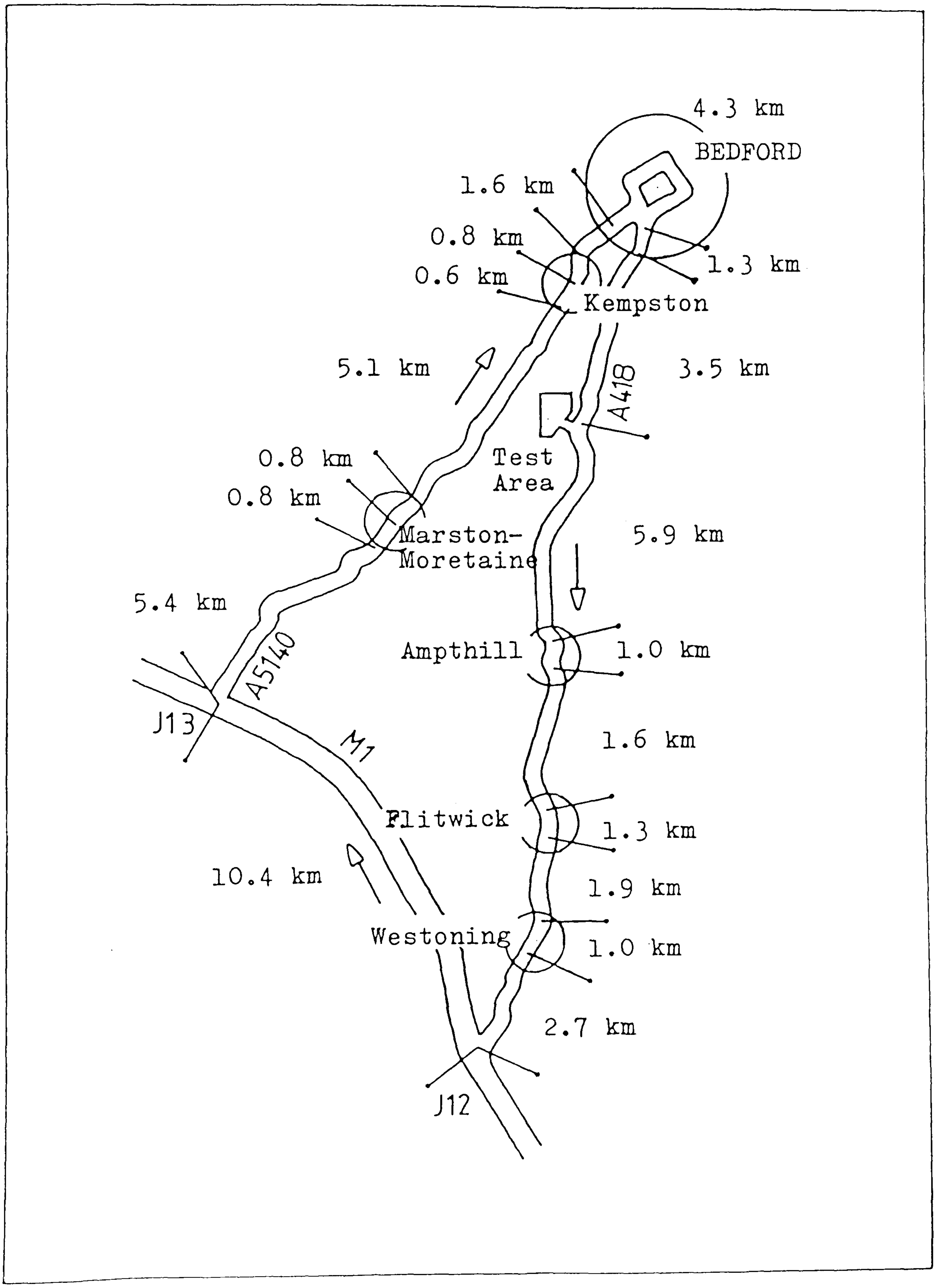
PERIODS WHEN NOT AVAILABLE (E.G. HOLIDAYS)______________________

	MON	TUE	WED	THU	FRI	SAT	SUN
AM							
PM							
EVENING							

✓ INDICATES NORMALLY AVAILABLE, X INDICATES NOT NORMALLY AVAILABLE

ANYTIME ☐

APPENDIX F . Sketch map of the test route used during the Evaluation Study. The route is approximately 50 kilometres long.(not drawn to scale).



APPENDIX G. Data sheet used to record time, number of fine and coarse steering reversals, and a number of observational data (defined overleaf) during the road-runs.

SUBJECTS NAME.................. P.A.S........ RUN NO....

Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Totals
Hand position.																			
Technique.																			
Grip.																			
Arm position.																			
Posture.																			
Time.																			
Fine steer.																			
Coarse steer.																			
Rapid reversals.																			
Wheel in curb.																			
Corner cutting.																			
Hold back (1) Veh.																			
(2) Cyc.																			
Squeeze by (1) Veh.																			
(2) Cyc.																			
Courtesy (1) Stop																			
(2) Slow																			
(3) Wait																			
Rapid (1) Stop																			
(2) Slow																			
Overtake (1) Comp.																			
(2) Ext.																			
(3) Abht.																			
(4) Unhd.																			
Lane change.																			

APPENDIX G. Cont'd.

The first five variables which appear on the data sheet shown on the previous page were recorded only at the end of sections 1, 5, 8, 12 and 18. These variables may be defined as follows:

Hand Position. This was recorded in terms the position of the numbers on a clock face. Thus, the entry 10/2 would indicate that the subject was driving with his hands in the classic 'ten to two' position.

Technique. This was recorded as either 'hand over hand' (H/H) or 'feeding' (F), depending on whether the subject crossed his hands when steering or passed the wheel through his hands in a feeding motion.

Grip. The subject's grip on the steering wheel was recorded as being either firm (F) or loose (L).

Arm Position. The subject's arm position was recorded in terms of the angle between forearm and upper arm. If this angle was estimated to be between 150 and 160 degrees, the experimenter recorded the arm position as straight (S). If the angle was estimated to be less than 150 degrees, the subject's arm position was recorded as bent (B).

Posture. This was recorded in terms of the angle between the subject's back and the horizontal. An estimated angle greater than 90 degrees was recorded as 'forward' (F), an angle of 90 degrees was recorded as 'erect' (E), and an angle estimated to be less than 90 degrees was recorded as 'reclining' (R).

The following variables were recorded from instruments in the car at the end of each section:

Time. This was recorded in minutes and seconds from the electronic stop watch.

Fine Steer. The number of fine steering reversals was recorded from the steering reversals counter fitted on the

APPENDIX G. <u>Cont'd</u>.

dashboard immediately in front of the experimenter.
<u>Coarse Steer</u>. The number of coarse steering reversals was also recorded from the display on the steering reversals counter.

The following variables were also recorded on each section of the route:

<u>Rapid Reversals</u>. These were the result of the tendency to 'oversteer' described by subjects in the Pilot Study. Each time the subject made a steering input which was followed by a rapid and significant corrective movement, a 'rapid reversal' was recorded.
<u>Wheel in Curb</u>. This item was endorsed each time the near-side wheels touched the curb or were placed on the road edge.
<u>Corner Cutting</u>. This item was endorsed each time the experimenter judged that the off-side wheels of the car crossed the white line when the subject was cornering.
<u>Hold Back</u>. Holding back was defined as the subject's refusal to enter a gap (1) between two vehicles which the experimenter judged would leave the driver with at least half a metre at each side of the car, or (2) between a cyclist and a vehicle which the experimenter judged would leave the driver with at least a metre between his car and the cyclist and at least half a metre between himself and the other vehicle.
<u>Squeeze By</u>. This item was endorsed each time the subject entered a gap judged to be smaller than those defined in Hold Back (1) and (2) above.
<u>Courtesy</u>. Courtesy was defined as giving way to another road-user when not required to do so by law, and was qualified in terms of (1) stopping to give way, (2) slowing down to give way, or (3) waiting when already stopped in order to allow another road-user priority.

APPENDIX G. Cont'd.

Rapid (1) Stop. This was defined as asevere braking manoeuvre indicating a lack of anticipation or emergency behaviour on the driver's part.

(2) Slow. This was defined as above but did not require the car to come to a standstill.

Overtake (1) Compressed. A 'compressed' overtaking manoeuvre was one in which the driver was forced to 'cut in' on the vehicle he was overtaking because of oncoming traffic.

(2) Extended. An overtaking manoeuvre involving more than one vehicle being overtaken.

(3) Aborted. This item was endorsed each time the subject began an overtaking manoeuvre by accelerating and pulling out but was forced to decelerate and return to his own lane by oncoming traffic.

(4) Unhurried. This item was endorsed each time the subject was able to carry out an overtaking manoeuvre in a relaxed and comfortable manner.

The last variable which appears on the road drive data sheet was recorded only on the motorway (section 8) and this was defined as follows:

Lane Change. This item was endorsed each time the subject changed lanes, either to the right or to the left, on the motorway.

APPENDIX H. Layout of the Test-track.

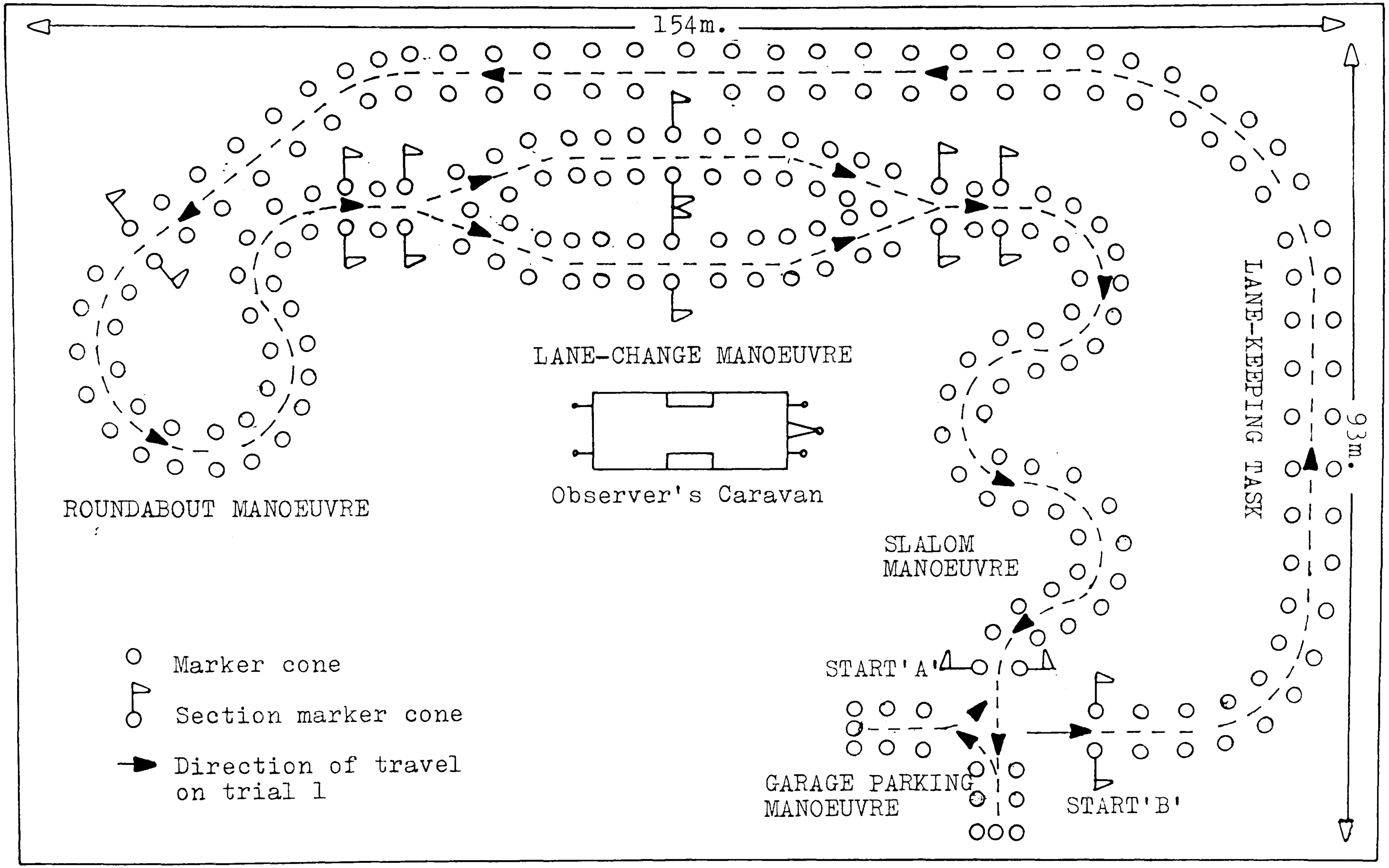


FIGURE 1. Overall plan view of the Test-track layout.

APPENDIX H. Cont'd.

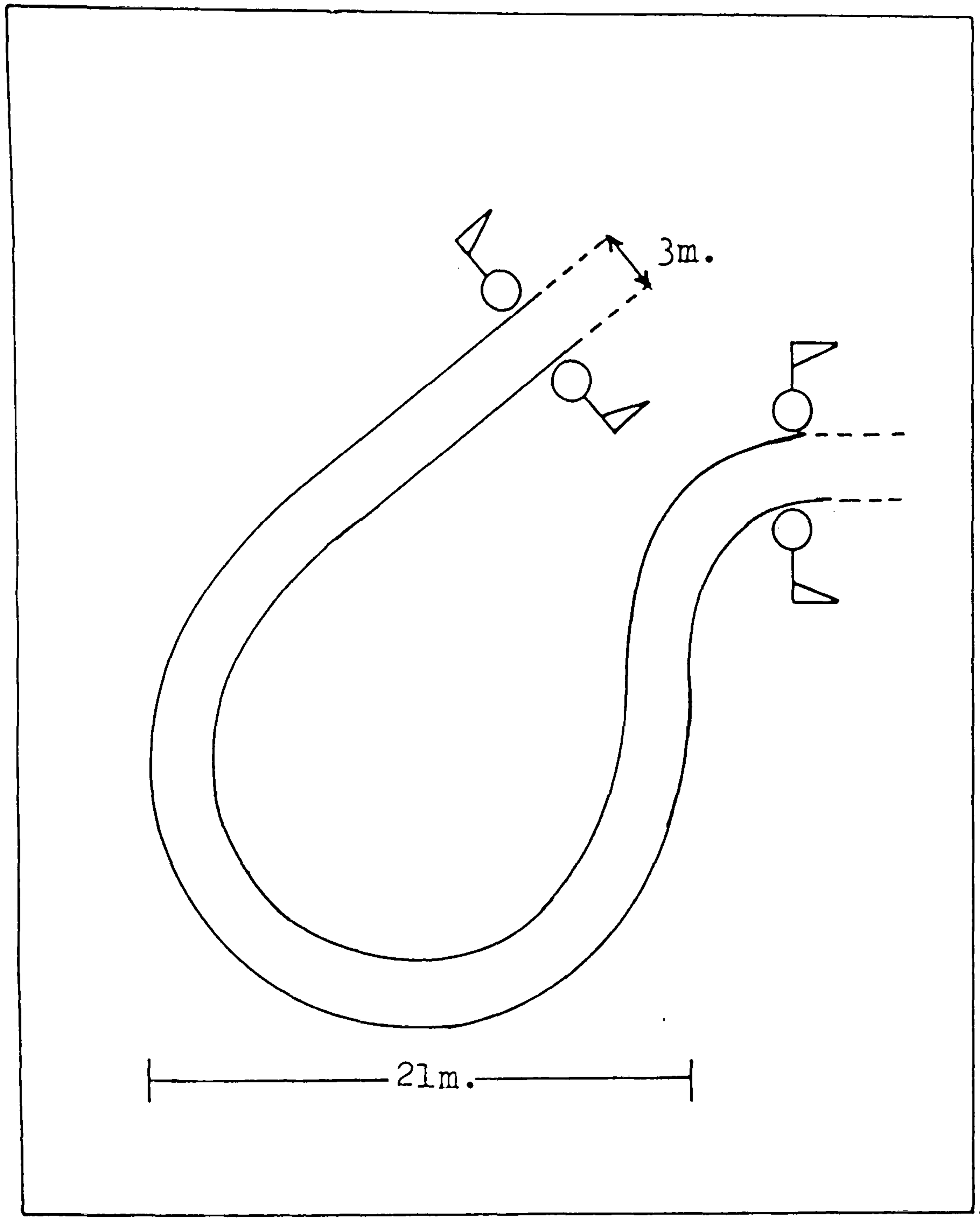


FIGURE 2. The Roundabout Manoeuvre.

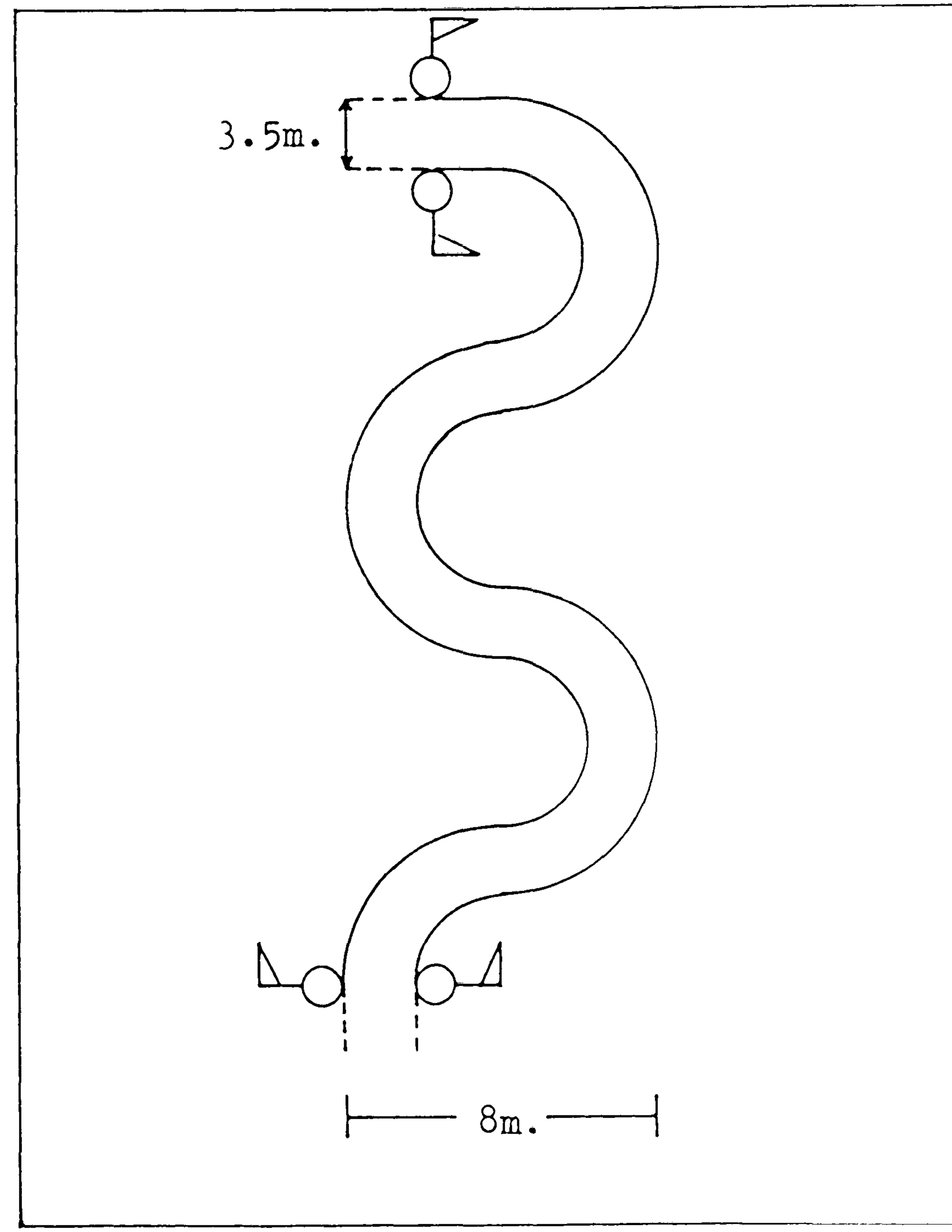


FIGURE 3. The Slalom Manoeuvre.

APPENDIX H. Cont'd.

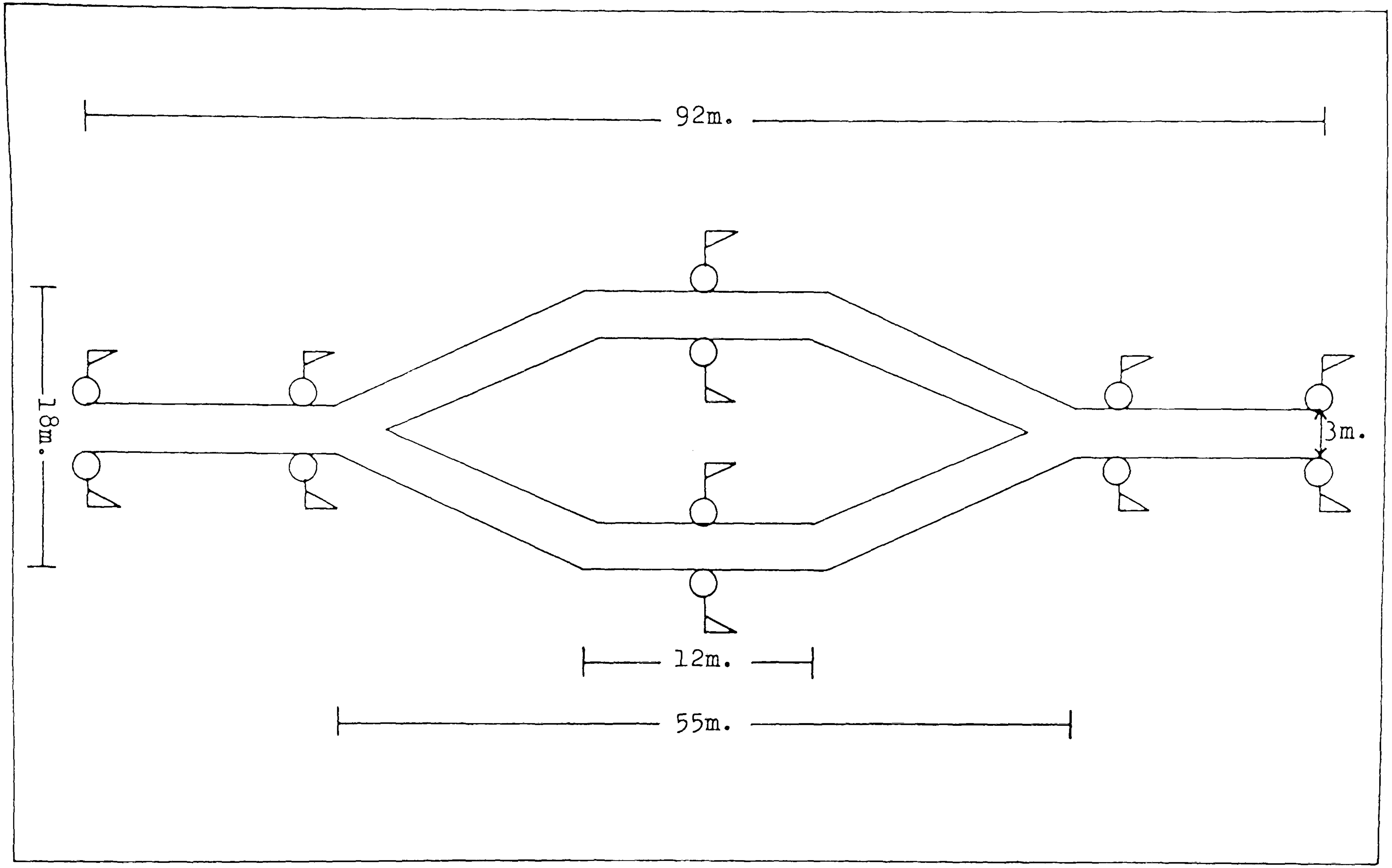


FIGURE 4. The Lane-Change Manoeuvre.

APPENDIX H. Cont'd.

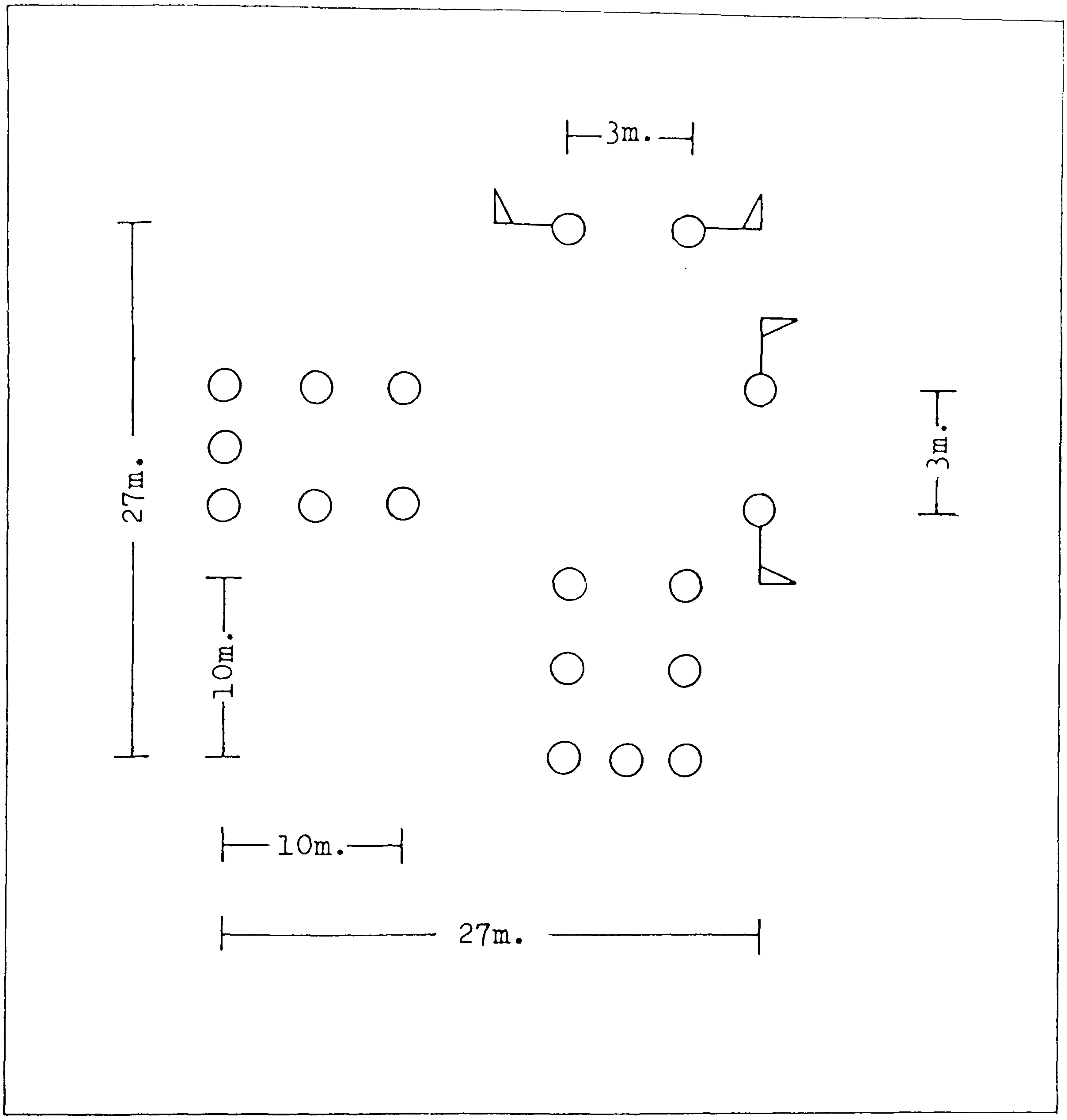


FIGURE 5. The Garage Parking Manoeuvre.

APPENDIX I . Pearson Product Moment correlation coefficients between the derived factors (Facs) and the simplified factors (NFacs) from Factor Analyses A to F.

	Factor Analysis A	B	C	D	E	F
Fac/NFac 1	.90	.87	.98	.98	.96	.92
Fac/NFac 2	.88	.86	.86	.80	.97	.98
Fac/NFac 3	.84	.84	.84	.85	.95	.96
Fac/NFac 4	.86	.86	.78	.69	.67	.67
Fac/NFac 5	.76	.84	.85	.85	.58	.94
Fac/NFac 6	.94	.74	.95	.82	.95	.94
Fac/NFac 7	.90	.89	.90	.80	.93	.91
Fac/NFac 8	.90	.78	.90	.90		
Fac/NFac 9	.89	.91	.89	.88		
Fac/NFac 10	.81	.69	.89	.86		
Fac/NFac 11	.89	.88	.78	.88		
Fac/NFac 12	.74	.52	.90	.89		
Fac/NFac 13	.84	.90	.83	.87		
Fac/NFac 14	.83	.88	.89	.92		
Fac/NFac 15	.92	.64	.83	.92		
Fac/NFac 16	.77	.90	.82			
Fac/NFac 17	.85	.75				
Fac/NFac 18	.80					
Fac/NFac 19	.87					

Values of $r \geq .20$ are significant at the 5 % level, values of $r \geq .26$ are significant at the 1% level.*

APPENDIX J . Pearson Product Moment intercorrelations between the NFactors from Factor Analyses A,B,C,D,E and F.

Table 1. Pearson Product Moment intercorrelations between the NFactors from Factor Analysis A.

	1A	2A	3A	4A	5A	6A	7A	8A	9A	10A	11A	12A	13A	14A	15A	16A	17A	18A	19A
1A	1.00	.62	-.58	-.47	.62	-.17	-.34	-.27	.40	-.32	-.30	-.52	-.30	-.03	-.03	.54	-.08	.32	-.14
2A	-	1.00	-.40	-.48	.70	-.08	-.31	-.24	.19	-.45	-.37	-.64	-.10	-.10	-.10	.40	-.00	.36	-.02
3A	-	-	1.00	.52	-.44	.21	.28	.18	-.08	.23	.13	.28	.57	.14	.14	-.31	-.10	-.21	.16
4A	-	-	-	1.00	-.46	.04	.30	.16	-.04	.43	.12	.37	.24	.02	.02	-.38	-.04	-.13	.12
5A	-	-	-	-	1.00	.06	-.38	-.21	.12	-.37	-.29	-.62	-.16	-.11	-.11	.45	.14	.32	-.00
6A	-	-	-	-	-	1.00	.12	.20	-.18	.17	.08	.09	.25	-.01	-.01	-.06	-.39	-.10	.12
7A	-	-	-	-	-	-	1.00	.28	-.03	.21	.18	.21	.12	.19	.19	-.45	.12	-.27	-.04
8A	-	-	-	-	-	-	-	1.00	-.15	.39	.21	.18	.07	-.12	-.12	-.21	-.02	-.16	-.02
9A	-	-	-	-	-	-	-	-	1.00	-.08	-.07	-.30	-.10	.07	.07	.12	-.08	.19	.03
10A	-	-	-	-	-	-	-	-	-	1.00	.27	.32	.01	-.04	-.04	-.30	.08	-.06	.02
11A	-	-	-	-	-	-	-	-	-	-	1.00	.25	-.16	-.01	-.01	.00	.07	.10	-.09
12A	-	-	-	-	-	-	-	-	-	-	-	1.00	.15	-.08	-.08	-.38	.02	-.20	.04
13A	-	-	-	-	-	-	-	-	-	-	-	-	1.00	-.06	-.06	-.24	-.07	-.17	.21
14A	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	.15	-.17	.07	-.21	-.15
15A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	.00	-.07	-.36	-.28
16A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	-.04	.32	-.19
17A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	.02	.06
18A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	.12
19A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00

Values of $r \geq .20$ are significant at the 5% level, values of $r \geq .26$ are significant at the 1% level*.

APPENDIX J. Cont'd.

Table 2. Pearson Product Moment intercorrelations between the NFactors from Factor Analysis B.

	1B	2B	3B	4B	5B	6B	7B	8B	9B	10B	11B	12B	13B	14B	15B	16B
1B	1.00	.42	.31	.53	.36	.09	.33	.28	.22	.32	.46	.43	.40	.31	.27	.38
2B	-	1.00	.45	.44	.26	.04	.33	.21	.20	.23	.37	.21	.43	.31	.35	.10
3B	-	-	1.00	.42	.26	.08	.24	.14	.29	.41	.40	.16	.38	.08	.20	.01
4B	-	-	-	1.00	.30	.16	.36	.37	.26	.22	.44	.34	.39	.20	.15	.22
5B	-	-	-	-	1.00	.27	.23	.29	.09	.15	.41	.16	.28	.24	.01	.11
6B	-	-	-	-	-	1.00	.23	.13	.04	-.18	.15	-.05	.08	-.05	.02	-.12
7B	-	-	-	-	-	-	1.00	.15	.26	.12	.30	.13	.37	.21	.02	.04
8B	-	-	-	-	-	-	-	1.00	-.02	.04	.16	.19	.01	.12	.12	.27
9B	-	-	-	-	-	-	-	-	1.00	.09	.29	.23	.32	.10	.04	.02
10B	-	-	-	-	-	-	-	-	-	1.00	.18	.14	.10	.07	.05	.19
11B	-	-	-	-	-	-	-	-	-	-	1.00	.23	.35	.24	.08	.02
12B	-	-	-	-	-	-	-	-	-	-	-	1.00	.16	.10	.07	.17
13B	-	-	-	-	-	-	-	-	-	-	-	-	1.00	.07	.30	-.02
14B	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	-.02	.22
15B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	.17
16B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00

Values of $r \geq .20$ are significant at the 5% level, values of $r \geq .26$ are significant at the 1% level*.

APPENDIX J. Cont'd.

Table 3. Pearson Product Moment intercorrelations between the NFactors from Factor Analysis C.

	1C	2C	3C	4C	5C	6C	7C
1C	1.00	.22	.28	.71	.76	.15	.14
2C	-	1.00	.44	.47	.13	-.05	.08
3C	-	-	1.00	.49	.13	-.02	-.12
4C	-	-	-	1.00	.63	.01	.10
5C	-	-	-	-	1.00	.10	.09
6C	-	-	-	-	-	1.00	.13
7C	-	-	-	-	-	-	1.00

Values of r = .20 are significant at the 5% level, values of r = .26 are significant at the 1% level*.

APPENDIX J. Cont'd.

Table 4. Pearson Product Moment intercorrelations between the NFactors from Factor Analysis D.

	1D	2D	3D	4D	5D	6D	7D	8D	9D	10D	11D	12D	13D	14D	15D	16D	17D
1D	1.00	.73	-.51	-.21	-.37	-.55	-.38	-.47	.06	-.54	-.18	-.79	.22	.08	.64	-.21	-.44
2D	-	1.00	-.52	-.36	-.50	-.51	-.27	-.47	-.08	-.65	-.12	-.82	.16	.05	.62	-.19	-.43
3D	-	-	1.00	.41	.52	.68	.39	.35	-.02	.59	.20	.65	-.06	.24	-.62	.03	.39
4D	-	-	-	1.00	.38	.28	-.01	.49	.09	.52	-.12	.42	-.20	.17	-.54	-.18	.41
5D	-	-	-	-	1.00	.38	.18	.31	.27	.41	.17	.55	-.19	.28	-.44	-.04	.25
6D	-	-	-	-	-	1.00	.42	.32	-.13	.59	.24	.57	.08	-.08	-.54	.14	.47
7D	-	-	-	-	-	-	1.00	.20	-.10	.24	.13	.33	.00	.05	-.30	.02	.29
8D	-	-	-	-	-	-	-	1.00	.15	.47	-.36	.54	-.19	.17	-.42	-.05	.48
9D	-	-	-	-	-	-	-	-	1.00	-.01	-.10	.05	-.08	.20	.01	-.20	-.17
10D	-	-	-	-	-	-	-	-	-	1.00	.05	.70	-.17	-.04	-.64	.12	.51
11D	-	-	-	-	-	-	-	-	-	-	1.00	.17	.15	-.10	-.12	.23	.01
12D	-	-	-	-	-	-	-	-	-	-	-	1.00	-.17	.06	-.69	.14	.56
13D	-	-	-	-	-	-	-	-	-	-	-	-	1.00	.04	.16	-.13	-.07
14D	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	.02	-.12	.00
15D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	-.06	-.53
16D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	-.07
17D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00

Values of $r \geq .20$ are significant at the 5% level, values of $r \geq .26$ are significant at the 1% level*.

APPENDIX J.Cont'd.

Table 5. Pearson Product Moment intercorrelations between the NFactors from Factor Analysis E.

	1E	2E	3E	4E	5E	6E	7E	8E	9E	10E	11E	12E	13E	14E	15E
1E	1.00	.42	.39	.50	.34	.55	.14	.40	.33	-.20	.10	.39	.02	.29	.22
2E	-	1.00	.17	.52	.21	.35	.28	.22	.48	-.15	.22	.27	.01	.33	.31
3E	-	-	1.00	.21	.22	.39	-.02	.12	.12	-.37	-.19	.10	.04	.05	.06
4E	-	-	-	1.00	.06	.24	.01	.22	.26	-.28	.02	.13	.30	.16	.11
5E	-	-	-	-	1.00	.35	-.02	.31	.10	-.15	.12	.18	.00	.18	.01
6E	-	-	-	-	-	1.00	.01	.15	.17	-.10	.01	.20	.09	.21	.09
7E	-	-	-	-	-	-	1.00	.00	.09	.02	.15	.17	-.62	.06	.04
8E	-	-	-	-	-	-	-	1.00	.14	-.13	.01	.20	.05	.06	.04
9E	-	-	-	-	-	-	-	-	1.00	-.17	.05	.13	-.02	.22	.07
10E	-	-	-	-	-	-	-	-	-	1.00	.45	.13	.03	-.02	.18
11E	-	-	-	-	-	-	-	-	-	-	1.00	.28	-.03	.19	.28
12E	-	-	-	-	-	-	-	-	-	-	-	1.00	.00	.14	.20
13E	-	-	-	-	-	-	-	-	-	-	-	-	1.00	.05	.05
14E	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	.12
15E	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00

Values of r ≥ .20 are significant at the 5% level, values of r ≥ .26 are significant at the 1% level*.

APPENDIX J. Cont'd.

Table 6. Pearson Product Moment intercorrelations between the NFactors from Factor Analysis F.

	1F	2F	3F	4F	5F	6F	7F
1F	1.00	.06	.25	.76	-.06	-.05	-.09
2F	-	1.00	.38	.22	.00	-.04	-.15
3F	-	-	1.00	.19	-.08	-.16	-.20
4F	-	-	-	1.00	-.03	-.10	-.02
5F	-	-	-	-	1.00	.21	.33
6F	-	-	-	-	-	1.00	.30
7F	-	-	-	-	-	-	1.00

Values of $r \geq .20$ are significant at the 5% level, values of $r \geq .26$ are significant at the 1% level*.

* These critical values of r were calculated from the following formula given by Hays (1973) p.661:

$$t = \frac{r_{xy}\sqrt{N-2}}{\sqrt{1-r^2_{xy}}}$$

where N = 100, and the degrees of freedom for the t ratio are N - 2. The values of r calculated are those required for t to be significant at the 5% and 1% levels (two tailed test).

APPENDIX K . List of variables included in the factor analyses of Road-run data.

Variable Number	Variable Type	Section of the Route	Variable Number	Variable Type	Section of the Route
1	Time	1. Test Area to Ampthill	28	Time	10. Marston, urban
2	Fine Steer		29	Fine Steer	"
3	Coarse Steer	"	30	Coarse Steer	
4	Time	2. Ampthill	31	Time	11. Marston, suburban
5	Fine Steer	"	32	Fine Steer	"
6	Coarse Steer	"	33	Coarse Steer	"
7	Time	3. Ampthill to Flitwick	34	Time	12. Marston to Kempston
8	Fine Steer		35	Fine Steer	
9	Coarse Steer	"	36	Coarse Steer	"
10	Time	4. Ampthill, urban	37	Time	13. Kempston round-about
11	Fine Steer	"	38	Fine Steer	
12	Coarse Steer	"	39	Coarse Steer	"
13	Time	5. Flitwick to Westoning	40	Time	14. Kempston, urban
14	Fine Steer		41	Fine Steer	"
15	Coarse Steer	"	42	Coarse Steer	"
16	Time	6. Westoning	43	Time	15. Kempston to Bedford
17	Fine Steer	"	44	Fine Steer	
18	Coarse Steer	"	45	Coarse Steer	"
19	Time	7. Westoning to M1	46	Time	16. Bedford, urban
20	Fine Steer	"	47	Fine Steer	
21	Coarse Steer	"	48	Coarse Steer	"
22	Time	8. M1 motorway	49	Time	17. Bedford, Ampthill Road
23	Fine Steer	"	50	Fine Steer	
24	Coarse Steer	"	51	Coarse Steer	"
25	Time	9. M1 to Marston	52	Time	18. Bedford to Test-Area
26	Fine Steer	"	53	Fine Steer	
27	Coarse Steer	"	54	Coarse Steer	"

APPENDIX L . List of variables included in the factor analyses of Test-track data.

Variable Number	Variable Type	Trial Number	Variable Number	Variable Type	Trial Number
1	Time	1	19	Time	5
2	Cones	"	20	Cones	"
3	Fine Steer	"	21	Fine Steer	"
4	Coarse Steer	"	22	Coarse Steer	"
5	Time	2	23	Subsidiary Task	"
6	Cones	"	24	Time	6
7	Fine Steer	"	25	Cones	"
8	Coarse Steer	"	26	Fine Steer	"
9	Subsidiary Task	"	27	Coarse Steer	"
10	Time	3	28	Time	7
11	Cones	"	29	Cones	"
12	Fine Steer	"	30	Fine Steer	"
13	Coarse Steer	"	31	Coarse Steer	"
14	Time	4	32	Subsidiary Task	"
15	Cones	"	33	Time	8
16	Fine Steer	"	34	Cones	"
17	Coarse Steer	"	35	Fine Steer	"
18	Subsidiary Task	"	36	Coarse Steer	"

APPENDIX M. Means and standard deviations of the variables included in Factor Analyses A to F.

Table 1. Means and standard deviations for each of the variables included in Factor Analysis A (items from Questionnaire B*).

Item	Mean	Standard Deviation	Item	Mean	Standard Deviation
1	2.9	0.30	37	3.4	0.67
2	4.0	1.00	38	3.0	0.68
3	3.7	0.99	39	3.1	0.51
4	1.5	0.73	40	3.1	0.70
5	3.1	1.00	41	3.3	0.74
6	2.9	1.06	42	2.8	0.68
7	4.4	0.74	43	2.6	0.74
8	2.9	1.05	44	2.7	0.87
9	3.0	0.85	45	3.3	1.00
10	3.5	0.81	46	3.0	0.55
11	3.2	0.95	47	2.7	0.79
12	3.2	0.54	48	3.0	0.53
13	2.9	0.51	49	3.2	0.71
14	3.0	0.49	50	3.1	0.67
15	2.7	0.82	51	2.6	0.71
16	3.1	0.60	52	2.5	0.77
17	2.9	0.60	53	2.6	0.79
18	3.4	0.54	54	2.5	0.88
19	3.2	1.00	55	3.0	0.97
20	3.0	0.72	56	1.9	0.73
21	4.2	0.73	57	1.9	0.58
22	3.1	0.61	58	2.2	0.65
23	3.1	0.49	59	1.4	0.59
24	2.8	0.68	60	3.4	0.64
25	2.9	0.56	61	4.0	0.70
26	3.1	0.88	62	3.2	0.94
27	2.8	0.79	63	2.5	0.70
28	3.6	0.84	64	3.5	0.60
29	2.8	0.73	65	4.2	0.66
30	3.4	0.77	66	2.8	0.65
31	4.0	0.73	67	3.5	0.87
32	3.4	0.50	68	3.3	0.71
33	2.7	0.81	69	2.9	0.60
34	3.4	0.87	70	3.3	0.62
35	3.1	0.84	71	3.2	0.74
36	3.2	0.94			

* Items on the questionnaire were numbered from 1 to 69 (see Appendix B). Item 57 was in three parts, however, providing a total of 71 variables for inclusion in Factor Analysis A.

APPENDIX M. Cont'd.

Table 2. Means and Standard Deviations for each of the Road-run variables*included in Factor Analysis B (Road-run 1).

Variable	Mean	Standard Deviation	Variable	Mean	Standard Deviation
1	5.4	0.8	28	0.9	0.2
2	73.6	26.1	29	10.4	4.4
3	12.1	4.3	30	3.8	1.0
4	2.0	0.6	31	0.8	0.1
5	27.6	14.2	32	10.3	3.8
6	11.1	3.2	33	2.4	1.2
7	1.9	0.4	34	4.4	0.5
8	24.8	7.5	35	61.5	22.7
9	6.7	2.2	36	9.8	3.0
10	1.9	0.3	37	1.1	0.2
11	24.7	7.5	38	12.7	4.9
12	10.2	2.2	39	5.4	1.5
13	2.2	0.4	40	2.1	0.5
14	31.8	9.2	41	21.2	7.9
15	9.6	2.0	42	8.5	2.9
16	1.1	0.2	43	2.2	0.3
17	13.3	4.2	44	28.6	10.3
18	4.2	1.3	45	7.1	2.4
19	2.6	0.3	46	9.5	1.3
20	32.5	11.4	47	114.4	29.8
21	6.6	2.7	48	44.7	7.6
22	6.5	0.7	49	1.6	0.2
23	87.2	34.6	50	23.9	8.1
24	3.9	2.8	51	5.3	2.4
25	4.7	0.6	52	3.3	0.4
26	68.8	25.7	53	45.1	15.5
27	8.3	3.7	54	6.8	2.3

* A list of these variables appears in Appendix K.

APPENDIX M. Cont'd.

Table 3. Means and Standard Deviations for each of the test-track variables*included in Factor Analysis C (Test-Track 1).

Variable	Mean	Standard Deviation	Variable	Mean	Standard Deviation
1	134.4	34.8	19	115.5	28.0
2	0.7	1.2	20	1.8	9.1
3	43.0	10.6	21	39.6	8.8
4	22.4	4.2	22	20.2	3.2
5	127.0	34.0	23	30.6	17.9
6	0.9	1.3	24	106.2	25.5
7	46.4	11.4	25	0.7	1.2
8	21.6	5.0	26	36.1	7.6
9	28.7	20.2	27	18.5	3.0
10	115.1	29.4	28	110.9	26.2
11	0.8	1.2	29	0.9	1.2
12	37.1	7.8	30	37.5	8.4
13	19.6	3.5	31	19.3	3.3
14	116.0	30.4	32	30.7	16.8
15	0.9	1.2	33	102.8	22.8
16	41.9	9.7	34	0.6	0.9
17	20.3	4.3	35	34.0	6.7
18	29.8	19.0	36	17.9	3.3

* A list of these variables appears in Appendix L.

APPENDIX M. Cont'd.

Table 4. Means and standard deviations for each of the variables included in Factor Analysis D (items from Questionnaire C*).

Item	Mean	Standard Deviation	Item	Mean	Standard Deviation
1	2.5	0.52	37	3.6	0.66
2	3.1	0.92	38	3.6	0.60
3	3.0	0.91	39	2.9	0.58
4	3.1	0.49	40	3.4	0.61
5	3.8	0.76	41	3.6	0.65
6	2.5	0.82	42	2.7	0.60
7	2.3	0.66	43	3.2	0.48
8	3.2	0.82	44	2.8	0.83
9	2.6	0.64	45	2.6	0.91
10	2.5	0.76	46	2.9	0.43
11	2.6	0.80	47	3.2	0.81
12	2.9	0.40	48	2.8	0.60
13	3.2	0.39	49	2.6	0.64
14	3.1	0.41	50	3.3	0.54
15	3.2	0.56	51	2.5	0.66
16	2.9	0.44	52	2.5	0.70
17	3.2	0.49	53	2.6	0.64
18	2.8	0.41	54	2.5	0.77
19	3.7	0.80	55	2.6	0.87
20	2.6	0.64	56	2.8	0.86
21	2.3	0.63	57	2.3	0.86
22	3.1	0.37	58	1.2	0.46
23	3.0	0.35	59	1.1	0.33
24	2.8	0.65	60	3.6	0.56
25	2.9	0.49	61	3.4	0.69
26	2.7	0.80	62	3.7	0.78
27	3.3	0.70	63	2.9	0.57
28	3.4	0.70	64	2.9	0.40
29	2.6	0.73	65	2.2	0.61
30	3.7	0.73	66	3.1	0.63
31	2.4	0.68	67	3.6	0.73
32	2.9	0.31	68	3.1	0.54
33	3.5	0.77	69	3.0	0.50
34	3.7	0.74	70	3.3	0.60
35	2.6	0.70	71	3.2	0.71
36	2.6	0.78			

* Items on the questionnaire were numbered from 1 to 69 (see Appendix B). Item 57 was in three parts, however, providing a total of 71 variables for inclusion in Factor Analysis D.

APPENDIX M. Cont'd.

Table 5. Means and Standard Deviations for each of the road-run variables*included in Factor Analysis E (Road-run 2).

Variable	Mean	Standard Deviation	Variable	Mean	Standard Deviation
1	5.2	0.8	28	1.0	0.8
2	73.6	24.8	29	10.0	3.3
3	12.6	6.9	30	4.3	1.2
4	2.0	0.7	31	1.0	1.2
5	25.0	11.0	32	10.3	4.1
6	11.7	3.8	33	2.3	1.2
7	1.8	0.4	34	4.2	0.5
8	24.0	9.0	35	60.3	23.5
9	6.5	2.5	36	10.5	10.5
10	1.8	0.2	37	1.1	0.3
11	22.7	8.1	38	12.3	5.0
12	10.1	2.2	39	5.7	1.5
13	2.2	0.4	40	2.1	0.5
14	29.6	9.1	41	21.0	7.6
15	10.4	2.5	42	8.6	3.0
16	1.0	0.2	43	2.3	0.5
17	13.4	6.4	44	30.8	11.6
18	4.5	1.6	45	8.6	3.8
19	2.6	0.4	46	10.6	2.1
20	33.1	13.3	47	120.2	34.4
21	6.5	2.8	48	49.3	10.0
22	6.2	0.6	49	1.6	0.2
23	83.3	32.7	50	24.4	8.0
24	3.5	2.3	51	6.3	2.9
25	4.5	0.5	52	3.3	0.4
26	65.3	24.2	53	45.9	14.2
27	8.1	3.4	54	7.1	2.8

* A list of these variables appears in Appendix K.

APPENDIX M. Cont'd.

Table 6. Means and Standard Deviations for each of the test-track variables*included in Factor Analysis F (Test-track 2).

Variable	Mean	Standard Deviation	Variable	Mean	Standard Deviation
1	108.1	20.1	19	103.4	18.9
2	0.6	1.0	20	0.7	1.0
3	31.1	7.4	21	34.5	7.2
4	17.9	3.2	22	18.8	3.3
5	107.7	20.3	23	32.5	16.7
6	0.7	0.9	24	94.2	17.5
7	36.9	9.0	25	0.5	0.7
8	19.1	4.3	26	31.2	6.7
9	29.9	17.2	27	17.2	2.7
10	100.6	17.5	28	101.1	16.8
11	0.4	0.7	29	1.1	1.4
12	32.3	6.9	30	33.7	7.6
13	18.4	3.0	31	18.4	3.3
14	101.6	20.4	32	32.3	16.5
15	0.7	1.0	33	93.7	15.9
16	36.5	7.7	34	0.6	0.8
17	19.2	3.5	35	30.1	5.9
18	31.2	16.4	36	17.1	2.8

* A list of these variables appears in Appendix L.

APPENDIX N. Means and standard deviations of groups' scores on the variables included in Discriminant Analyses 1 to 16. (Means and standard deviations for the variables included in Discriminant Analyses 4, 8, 12 and 16 are not given separately since these analyses were performed on the combined variables from the three analyses preceding them).

Table 1. Means and standard deviations of groups' scores on the variables included in Discriminant Analysis 1 (NFacs 1A to 19A). Discriminant groups, males and females.

	Group 1 (Males)		Group 2 (Females)	
Variable	Mean	Standard Deviation	Mean	Standard Deviation
NFac 1A	0.30	5.82	- 0.44	5.55
NFac 2A	0.55	4.74	- 0.40	4.81
NFac 3A	0.30	3.20	- 0.30	3.31
NFac 4A	- 0.43	2.92	0.30	3.31
NFac 5A	0.32	3.08	- 0.58	3.00
NFac 6A*	0.56	2.28	- 0.68	2.67
NFac 7A*	- 0.56	2.43	0.58	1.94
NFac 8A	- 0.15	1.49	0.25	1.94
NFac 9A	- 0.33	1.52	0.30	1.62
NFac 10A	- 0.16	1.67	0.00	1.52
NFac 11A	0.03	1.48	- 0.03	1.72
NFac 12A	0.00	1.84	- 0.09	1.66
NFac 13A	0.16	1.68	- 0.19	1.85
NFac 14A*	0.28	1.40	- 0.31	1.52
NFac 15A	- 0.04	1.40	0.02	1.50
NFac 16A	0.22	1.47	- 0.31	1.33
NFac 17A	0.06	1.31	- 0.11	1.34
NFac 18A	0.09	1.16	0.05	1.27
NFac 19A	- 0.21	0.91	0.16	1.27

* Indicates that the univariate F ratio for this variable was significant at the 5% level.

APPENDIX N. Cont'd.

Table 2. Means and standard deviations of groups' scores on the variables included in Discriminant Analysis 2 (NFacs 1B to 16B). Discriminant groups, males and females.

Variable	Group 1 (Males) Mean	Group 1 (Males) Standard Deviation	Group 2 (Females) Mean	Group 2 (Females) Standard Deviation
NFac 1B	- 1.11	10.96	1.15	12.43
NFac 2B	- 0.31	2.10	0.27	1.94
NFac 3B*	- 0.48	1.21	0.58	1.90
NFac 4B*	- 0.40	1.65	0.42	1.75
NFac 5B	- 0.16	1.07	0.09	1.74
NFac 6B	- 0.45	1.66	- 0.02	1.50
NFac 7B	- 0.02	1.76	0.17	1.44
NFac 8B	0.02	1.53	- 0.24	1.33
NFac 9B	- 0.09	1.26	0.07	1.19
NFac 10B	0.19	1.68	- 0.01	1.25
NFac 11B	- 0.02	1.28	0.24	1.35
NFac 12B	- 0.04	1.59	0.09	1.68
NFac 13B*	- 0.34	1.39	0.34	1.26
NFac 14B	0.08	1.32	- 0.17	1.48
NFac 15B	- 0.16	1.31	0.04	1.10
NFac 16B	0.28	1.38	- 0.21	1.07

* Indicates that the univariate F ratio for this variable was significant at the 5% level.

APPENDIX N. Cont'd.

Table 3. Means and standard deviations of groups' scores on the variables included in Discriminant Analysis 3 (NFacs 1C to 7C). Discriminant groups, males and females.

Variable	Group 1 (Males) Mean	Group 1 (Males) Standard Deviation	Group 2 (Females) Mean	Group 2 (Females) Standard Deviation
NFac 1C	0.04	5.00	- 0.01	6.01
NFac 2C*	1.91	3.06	4.61	5.00
NFac 3C	- 0.02	2.92	0.02	3.57
NFac 4C	- 0.06	1.38	0.05	1.41
NFac 5C	0.06	1.15	- 0.05	1.31
NFac 6C*	- 0.20	0.76	0.20	1.07
NFac 7C*	- 0.33	0.49	0.33	1.11

* Indicates that the univariate F ratio for this variable was significant at the 5% level.

APPENDIX N. Cont'd.

Table 4. Means and standard deviations of groups' scores on the variables included in Discriminant Analysis 5 (NFacs 1D to 17D). Discriminant groups, males and females.

Variable	Group 1 (Males) Mean	Group 1 (Males) Standard Deviation	Group 2 (Females) Mean	Group 2 (Females) Standard Deviation
NFac 1D	- 0.42	5.03	0.26	5.10
NFac 2D	0.36	4.70	- 0.16	5.34
NFac 3D	- 0.10	3.29	- 0.02	3.11
NFac 4D	- 0.06	2.79	- 0.10	2.96
NFac 5D	- 0.19	2.58	0.06	2.91
NFac 6D	- 0.16	2.27	- 0.25	2.55
NFac 7D	- 0.20	2.00	0.05	2.10
NFac 8D	0.04	1.67	- 0.22	2.23
NFac 9D*	- 0.52	1.14	0.35	1.89
NFac 10D	- 0.19	1.98	0.02	2.07
NFac 11D	- 0.14	1.55	- 0.00	1.50
NFac 12D	0.11	2.48	- 0.07	2.75
NFac 13D	0.01	1.53	0.02	1.19
NFac 14D	0.05	1.28	0.06	1.78
NFac 15D	- 0.06	1.80	0.06	1.81
NFac 16D	- 0.06	1.26	- 0.15	1.36
NFac 17D	0.07	1.56	0.02	1.67

* Indicates that the univariate F ratio for this variable was significant at the 5% level.

APPENDIX N. Cont'd.

Table 5. Means and standard deviations of groups' scores on the variables included in Discriminant Analysis 6 (NFacs 1E to 15E). Discriminant groups, males and females.

Variable	Group 1 (Males)		Group 2 (Females)	
	Mean	Standard Deviation	Mean	Standard Deviation
NFac 1E	- 1.01	11.09	1.04	12.42
NFac 2E*	- 0.70	2.13	0.67	2.40
NFac 3E	0.21	1.78	- 0.20	1.19
NFac 4E*	- 0.32	1.31	0.35	2.01
NFac 5E	0.01	1.44	0.07	1.47
NFac 6E	0.06	1.67	- 0.10	1.57
NFac 7E	- 0.04	1.27	- 0.13	1.29
NFac 8E	- 0.19	1.29	0.34	1.83
NFac 9E*	- 0.36	1.18	0.18	1.52
NFac 10E	- 0.01	1.68	0.03	1.19
NFac 11E	- 0.04	1.19	0.20	1.30
NFac 12E	- 0.22	1.39	- 0.08	1.41
NFac 13E	- 0.01	1.27	0.10	1.48
NFac 14E	0.15	1.64	0.06	1.24
NFac 15E	- 0.18	1.19	- 0.07	1.37

* Indicates that the univariate F ratio for this variable was significant at the 5% level.

APPENDIX N. Cont'd.

Table 6. Means and standard deviations of groups' scores on the variables included in Discriminant Analysis 7 (NFacs 1F to 7F). Discriminant groups, males and females.

	Group 1 (Males)		Group 2 (Females)	
Variable	Mean	Standard Deviation	Mean	Standard Deviation
NFac 1F	1.04	7.77	- 1.09	8.00
NFac 2F*	- 2.33	5.47	2.33	7.01
NFac 3F	0.08	3.07	- 0.08	3.91
NFac 4F	0.21	1.48	- 0.23	1.94
NFac 5F*	- 0.32	0.65	0.32	1.07
NFac 6F*	- 0.20	0.70	0.20	1.10
NFac 7F	- 0.08	0.78	0.08	1.02

* Indicates that the univariate F ratio for this variable was significant at the 5% level.

APPENDIX N. Cont'd.

Table 7. Means and standard deviations of groups' scores on the variables included in Discriminant Analysis 9 (NFacs 1D to 17D). Discriminant groups, power steering groups 1 to 5.

Variable	Group 1 (Load Spring Heavy) Mean	Group 1 Standard Deviation	Group 2 (Load Spring Light) Mean	Group 2 Standard Deviation	Group 3 (Speed Prop. Feel) Mean	Group 3 Standard Deviation	Group 4 (Con. Reaction) Mean	Group 4 Standard Deviation	Group 5 (Control group) Mean	Group 5 Standard Deviation
NFac 1D	0.51	5.55	0.16	4.26	- 2.23	4.68	0.61	5.45	0.55	5.11
NFac 2D	0.54	5.21	0.14	4.14	- 2.39	4.94	1.39	4.73	0.83	5.54
NFac 3D	- 0.27	3.19	0.23	3.34	0.48	3.59	- 0.58	3.46	- 0.14	2.43
NFac 4D	- 0.93	2.05	- 0.14	1.48	0.42	2.85	- 0.97	2.30	1.21	4.40
NFac 5D*	0.26	2.25	- 0.81	2.21	1.27	2.93	- 1.20	2.95	0.16	2.80
NFac 6D	- 0.10	2.25	- 0.37	2.69	- 0.21	2.00	- 0.48	2.97	0.13	2.18
NFac 7D	0.63	2.58	- 0.44	1.16	0.01	2.32	- 0.20	2.13	- 0.36	1.74
NFac 8D	- 0.68	2.64	- 0.23	1.89	- 0.06	1.40	- 0.33	2.10	0.82	1.37
NFac 9D	- 0.41	1.21	- 0.22	1.58	0.11	1.50	- 0.04	1.88	0.12	1.91
NFac 10D	0.04	1.68	- 0.11	1.98	0.33	2.35	- 0.73	1.78	0.04	2.26
NFac 11D	- 0.01	1.64	0.42	1.30	0.11	1.36	- 0.22	1.84	- 0.65	1.32
NFac 12D	- 0.32	2.40	0.07	2.30	0.94	2.30	- 0.36	2.67	- 0.21	2.68
NFac 13D	- 0.11	1.11	0.02	1.16	- 0.41	2.06	0.47	1.16	0.15	1.05
NFac 14D	- 0.03	1.84	- 0.09	1.14	0.36	1.36	- 0.37	1.59	0.41	1.69
NFac 15D	0.11	1.63	- 0.36	1.97	- 0.25	1.97	0.55	1.49	- 0.04	1.91
NFac 16D	0.11	1.52	0.02	1.48	- 0.32	1.06	0.27	1.29	- 0.61	1.05
NFac 17D	- 0.34	1.63	0.18	1.64	0.25	1.76	- 0.30	1.67	0.43	1.31

* Indicates that the univariate F ratio for this variable was significant at the 5% level.

APPENDIX N. Cont'd.

Table 8. Means and standard deviations of groups' scores on the variables included in Discriminant Analysis 10 (NFacs 1E to 15E). Discriminant groups, power steering groups 1 to 5.

Variable	Group 1(Load Spring Heavy) Mean	Standard Deviation	Group 2(Load Spring Light) Mean	Standard Deviation	Group 3(Speed Prop. Feel) Mean	Standard Deviation	Group 4(Con. Reaction) Mean	Standard Deviation	Group 5 (Control group) Mean	Standard Deviation
NFac 1E	- 3.06	8.00	- 1.47	13.34	0.55	11.60	- 0.33	11.24	4.39	13.61
NFac 2E*	- 0.86	1.92	- 0.27	2.01	0.00	2.80	- 0.48	2.26	1.55	2.15
NFac 3E	- 0.12	1.27	0.41	2.25	- 0.05	1.25	- 0.18	1.38	- 0.01	1.30
NFac 4E	- 0.59	1.05	- 0.04	1.39	0.24	1.51	- 0.33	1.17	0.79	2.74
NFac 5E	- 0.06	1.87	- 0.03	1.43	0.22	1.29	0.33	1.52	- 0.24	1.12
NFac 6E	- 0.34	1.68	0.44	2.27	0.08	1.47	- 0.02	1.25	- 0.24	1.21
NFac 7E	- 0.46	1.58	- 0.11	0.82	0.45	1.26	- 0.14	1.10	- 0.15	1.41
NFac 8E	- 0.30	0.98	- 0.12	1.17	- 0.33	1.08	0.56	2.43	0.56	1.76
NFac 9E*	- 0.66	1.00	- 0.41	1.25	0.40	1.75	- 0.40	1.33	0.63	1.08
NFac 10E	0.29	2.03	0.05	1.13	- 0.20	1.26	0.50	1.44	- 0.60	1.03
NFac 11E	- 0.31	0.58	0.34	1.52	0.10	0.95	0.35	1.34	- 0.06	1.54
NFac 12E	- 0.59	1.26	- 0.15	1.28	- 0.08	1.23	- 0.02	1.48	0.08	1.72
NFac 13E	- 0.15	1.06	0.39	1.28	- 0.49	1.30	0.32	1.60	0.15	1.52
NFac 14E	0.40	2.05	- 0.07	1.17	0.11	1.30	- 0.01	1.31	0.10	1.33
NFac 15E	- 0.26	1.13	- 0.38	0.96	- 0.20	1.06	- 0.13	1.68	0.37	1.42

* Indicates that the univariate F ratio for this variable was significant at the 5% level.

APPENDIX N. Cont'd.

Table 9. Means and standard deviations of groups' scores on the variables included in Discriminant Analysis 11 (NFacs 1F to 7F). Discriminant groups, power steering groups 1 to 5.

Variable	Group 1(Load Spring Heavy)		Group 2(Load Spring Light)		Group 3(Speed Prop. Feel)		Group 4(Con. Reaction)		Group 5 (Control group)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
NFac 1F	- 1.54	7.22	- 0.04	7.67	0.34	9.18	- 1.25	8.42	2.35	7.04
NFac 2F	0.01	9.07	- 1.11	4.95	1.73	7.54	- 0.02	5.72	- 0.61	5.62
NFac 3F	0.47	4.33	- 0.01	3.04	0.52	3.47	- 1.23	3.57	0.26	2.96
NFac 4F	0.07	2.20	- 0.17	1.56	- 0.12	1.77	- 0.38	1.69	0.56	1.33
NFac 5F	0.31	1.00	0.17	1.27	- 0.43	0.41	- 0.09	0.79	0.04	0.92
NFac 6F	0.08	1.06	0.27	1.31	- 0.21	0.57	0.08	0.85	- 0.21	0.72
NFac 7F	- 0.22	0.65	0.33	1.41	- 0.28	0.63	0.06	0.84	0.11	0.74

APPENDIX N. Cont'd.

Table 10. Means and standard deviations of group's scores on the variables included in Discriminant Analysis 13 (NFacs 1D to 17D). Discriminant groups, power steering groups 1 to 10.

Variable	Group 1 (Load Spring Heavy, Males)		Group 2 (Load Spring Heavy, Females)		Group 3 (Load Spring Light, Males)		Group 4 (Load Spring Light, Females)		Group 5 (Speed Prop. Feel, Males)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
NFac 1D	- 0.85	5.01	1.86	5.92	- 0.11	4.77	0.43	3.92	- 0.76	5.52
NFac 2D	0.91	4.65	0.16	5.94	- 0.81	4.14	1.08	4.13	- 0.43	4.97
NFac 3D	0.39	3.54	- 0.93	2.84	1.06	4.02	- 0.61	2.41	- 0.57	3.62
NFac 4D	- 1.19	1.57	- 0.68	2.50	- 0.06	1.70	- 0.23	1.31	0.64	3.84
NFac 5D	0.80	2.30	- 0.27	2.19	- 0.98	2.18	- 0.65	2.35	0.43	2.87
NFac 6D	0.41	2.22	- 0.62	2.28	0.33	2.98	- 1.07	2.32	- 0.94	0.98
NFac 7D	1.11	3.07	0.15	2.04	- 0.62	0.56	- 0.26	1.57	- 0.94	0.56
NFac 8D	- 0.42	2.20	- 0.93	3.13	- 0.21	1.83	- 0.25	2.04	- 0.31	1.73
NFac 9D	- 0.56	0.79	- 0.26	1.56	- 1.03	1.62	0.58	1.08	- 0.29	1.22
NFac 10D	0.78	1.67	- 0.70	1.40	- 0.37	2.22	0.14	1.79	- 0.35	2.75
NFac 11D	- 0.12	1.72	0.10	1.64	0.96	1.25	- 0.12	1.16	- 0.47	1.39
NFac 12D	0.48	1.42	- 1.12	2.95	0.44	3.62	- 0.31	2.28	- 0.01	2.42
NFac 13D	- 0.19	1.04	- 0.04	1.23	0.17	0.93	- 0.14	1.38	- 0.79	2.42
NFac 14D	- 0.27	2.15	0.21	1.54	0.24	1.03	- 0.42	1.19	0.07	0.66
NFac 15D	0.07	1.48	0.15	1.85	- 0.73	2.07	0.01	1.89	0.22	2.28
NFac 16D	0.33	1.12	- 0.11	1.88	0.70	1.48	- 0.67	1.18	- 0.41	0.86
NFac 17D	0.03	1.33	- 0.71	1.87	0.52	1.98	- 0.16	1.21	- 0.41	1.94

APPENDIX N. Cont'd.

Table 10. Cont'd.

Variable	Group 6 (Speed Prop. Feel, Females)		Group 7 (Con. Reaction, Males)		Group 8 (Con. Reaction, Females)		Group 9 (Control group Males)		Group 10 (Control group Females)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
NFac 1D	-3.71	3.32	-1.12	5.33	2.34	5.27	0.74	5.28	0.36	5.22
NFac 2D	-4.35	4.28	0.50	4.57	2.29	4.96	1.66	5.59	-0.01	5.66
NFac 3D	1.52	3.41	-0.29	3.34	-0.88	3.74	-1.09	1.66	0.82	2.78
NFac 4D	0.19	1.53	-0.68	1.34	-1.26	3.03	0.96	4.13	1.47	4.86
NFac 5D	2.11	2.89	-1.32	2.60	-1.08	3.40	0.14	2.73	0.18	3.02
NFac 6D	0.52	2.49	-0.38	3.15	-0.58	2.94	-0.22	1.40	0.50	2.78
NFac 7D	0.95	3.01	0.23	2.84	-0.63	1.04	-0.78	0.58	0.06	2.38
NFac 8D	0.19	1.00	0.41	0.58	-1.07	2.79	0.70	1.59	0.94	1.18
NFac 9D	0.52	1.70	-0.01	0.93	-0.06	2.57	-0.72	0.90	0.96	2.30
NFac 10D	1.00	1.76	-0.32	1.46	-1.14	2.04	-0.70	1.60	0.78	2.65
NFac 11D	0.70	1.10	-0.49	1.70	0.04	2.03	-0.59	1.40	-0.72	1.31
NFac 12D	1.89	1.83	0.42	2.14	-1.14	3.02	-0.76	2.59	0.35	2.77
NFac 13D	-0.04	1.67	0.40	1.43	0.54	0.88	0.46	1.32	-0.17	0.61
NFac 14D	0.64	1.82	-0.29	1.19	-0.44	1.98	0.48	0.94	0.34	2.27
NFac 15D	-0.72	1.58	-0.09	1.59	1.20	1.13	0.23	1.67	-0.31	2.18
NFac 16D	-0.24	1.28	-0.14	1.14	0.69	1.34	-0.80	1.27	-0.41	0.78
NFac 17D	0.91	1.34	-0.25	1.06	-0.35	2.18	0.47	1.36	0.39	1.34

APPENDIX N. Cont'd.

Table 11. Means and standard deviations of groups' scores on the variables included in Discriminant Analysis 14 (NFacs 1E to 15E). Discriminant groups, power steering groups 1 to 10.

Variable	Group 1 (Load Spring Heavy Males) Mean	Standard Deviation	Group 2 (Load Spring Heavy Females) Mean	Standard Deviation	Group 3 (Load Spring Light Males) Mean	Standard Deviation	Group 4 (Load Spring Light Females) Mean	Standard Deviation	Group 5 (Speed Prop. Feel Males) Mean	Standard Deviation
NFac 1E	- 3.56	8.40	- 2.56	8.00	- 2.29	17.26	- 0.65	8.71	- 0.42	9.89
NFac 2E**	- 1.37	1.79	- 0.36	2.01	- 1.11	1.60	0.56	2.10	- 1.10	2.26
NFac 3E	0.19	1.16	- 0.43	1.36	1.14	2.90	- 0.32	1.04	0.26	1.62
NFac 4E	- 0.71	1.27	- 0.47	0.83	- 0.22	1.68	0.14	1.10	- 0.16	1.18
NFac 5E	0.01	1.84	- 0.12	1.10	0.17	1.89	- 0.23	0.80	0.28	1.12
NFac 6E	- 0.37	1.35	- 0.32	2.03	0.95	3.01	- 0.08	1.13	- 0.10	0.97
NFac 7E	- 0.24	1.68	- 0.67	1.54	- 0.46	0.89	0.23	0.61	0.79	1.13
NFac 8E	- 0.61	0.95	0.01	0.95	- 0.11	1.48	- 0.12	0.84	- 0.53	0.83
NFac 9E**	- 0.85	1.05	- 0.46	0.97	- 0.62	1.02	- 0.20	1.46	- 0.50	1.34
NFac 10E	0.43	2.81	0.14	0.84	- 0.40	1.11	0.51	0.99	- 0.56	1.07
NFac 11E	- 0.51	0.57	- 0.11	0.56	- 0.30	1.02	1.00	1.72	- 0.09	0.99
NFac 12E	- 0.64	1.22	- 0.54	1.36	- 0.63	0.91	0.33	1.45	- 0.25	1.21
NFac 13E	- 0.36	1.15	0.06	0.99	0.51	1.14	0.27	1.45	- 0.71	1.08
NFac 14E	1.12	2.56	- 0.32	1.09	- 0.14	1.11	- 0.00	1.27	- 0.05	1.34
NFac 15E	- 0.66	0.96	0.13	1.20	- 0.59	0.96	- 0.18	0.97	- 0.26	1.17

* Indicates that the univariate F ratio for this variable was significant at the 1% level.

APPENDIX N. Cont'd.

Table 11. Cont'd.

Variable	Group 6 (Speed Prop. Feel, Females) Mean	Standard Deviation	Group 7 (Con. Reaction, Males) Mean	Standard Deviation	Group 8 (Con. Reaction, Females) Mean	Standard Deviation	Group 9 (Control group Males) Mean	Standard Deviation	Group 10 (Control group Females) Mean	Standard Deviation
NFac 1E	1.52	13.57	- 0.97	8.99	0.30	13.60	2.17	10.10	6.62	16.68
NFac 2E**	1.10	2.96	- 0.98	1.99	0.03	2.51	1.08	2.31	2.02	1.99
NFac 3E	- 0.37	0.67	- 0.37	1.52	0.00	1.26	- 0.16	1.01	0.14	1.58
NFac 4E	0.64	1.75	- 0.38	1.12	- 0.29	1.27	- 0.15	1.42	1.74	4.86
NFac 5E	0.15	1.50	0.08	1.47	0.58	1.61	- 0.47	0.79	- 0.01	1.38
NFac 6E	0.25	1.88	- 0.09	0.61	0.05	1.70	- 0.09	1.33	- 0.38	1.13
NFac 7E	0.11	1.35	- 0.20	1.22	- 0.08	1.03	- 0.08	1.17	- 0.23	1.69
NFac 8E	- 0.13	1.30	- 0.19	1.20	1.31	3.13	0.49	1.76	0.64	1.86
NFac 9E**	1.31	1.68	- 0.76	0.89	- 0.03	1.63	0.97	0.56	0.29	1.38
NFac 10E	0.17	1.39	0.87	1.48	0.12	1.38	- 0.39	1.02	- 0.81	1.05
NFac 11E	0.28	0.92	0.45	1.10	0.26	1.60	0.26	1.85	- 0.38	1.15
NFac 12E	0.10	1.28	0.27	1.70	- 0.31	1.25	0.15	1.75	0.01	1.77
NFac 13E	- 0.27	1.50	0.69	1.49	- 0.04	1.70	- 0.16	1.13	0.46	1.84
NFac 14E	0.28	1.32	- 0.33	0.90	0.31	1.60	0.16	1.66	0.04	0.98
NFac 15E	- 0.15	1.00	0.12	1.71	- 0.38	1.70	0.51	0.70	0.23	1.93

** Indicates that the univariate F ratio for this variable was significant at the 1% level.

APPENDIX N. Cont'd.

Table 12. Cont'd.

Variable	Group 6 (Speed Prop. Feel, Females) Mean	Standard Deviation	Group 7 (Con. Reaction, Males) Mean	Standard Deviation	Group 8 (Con. Rection, Females) Mean	Standard Deviation	Group 9 (Control group Males) Mean	Standard Deviation	Group 10 (Control group Females) Mean	Standard Deviation
NFac 1F	3.09	11.20	3.55	8.07	- 6.05	5.77	4.02	8.65	0.69	4.87
NFac 2F*	4.90	7.43	- 0.54	5.94	0.51	5.76	- 2.88	4.88	1.67	5.61
NFac 3F	1.66	3.54	0.19	4.07	- 2.66	2.39	1.40	2.36	- 0.88	3.17
NFac 4F	0.09	2.30	0.46	2.05	- 1.22	0.53	1.02	1.61	0.10	0.81
NFac 5F*	- 0.43	0.42	- 0.43	0.42	0.24	0.94	- 0.43	0.42	0.51	1.06
NFac 6F	- 0.16	0.50	0.22	1.00	- 0.07	0.68	- 0.46	0.31	0.03	0.94
NFac 7F	- 0.39	0.47	- 0.17	0.78	0.28	0.88	0.17	0.75	0.06	0.78

* Indicates that the univariate F ratio for this variable was significant at the 5% level.

APPENDIX N. Cont'd.

Table 12. Means and standard deviations of groups' scores on the variables included in Discriminant Analysis 15 (NFacs 1F to 7F). Discriminant groups, power steering groups 1 to 10.

Variable	Group 1 (Load Spring Heavy, Males) Mean	Standard Deviation	Group 2 (Load Spring Heavy, Females) Mean	Standard Deviation	Group 3 (Load Spring Light, Males) Mean	Standard Deviation	Group 4 (Load Spring Light, Females) Mean	Standard Deviation	Group 5 (Speed Prop. Feel, Males) Mean	Standard Deviation
NFac 1F	- 0.67	6.37	- 2.41	8.22	0.70	8.89	- 0.79	6.63	- 2.42	5.94
NFac 2F*	- 3.34	6.19	3.36	10.50	- 3.46	3.98	1.24	4.87	- 1.43	6.52
NFac 3F	- 0.78	1.79	1.72	5.74	0.20	3.53	- 0.21	2.63	- 0.62	3.17
NFac 4F	0.20	1.00	- 0.05	3.03	- 0.29	1.21	- 0.06	1.91	- 0.34	1.08
NFac 5F*	- 0.03	0.94	0.64	0.99	- 0.30	0.85	0.64	1.48	- 0.43	0.42
NFac 6F	- 0.26	0.65	0.42	1.29	- 0.26	0.65	0.80	1.60	- 0.26	0.65
NFac 7F	- 0.28	0.54	- 0.17	0.77	0.06	1.07	0.61	1.69	- 0.17	0.76

* Indicates that the univariate F ratio for this variable was significant at the 5% level.